The
SCIENTIFIC MONTHLY

VOL. 84 NO. 2

FEBRUARY 1957

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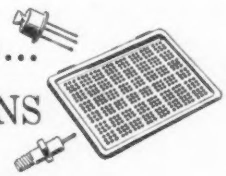
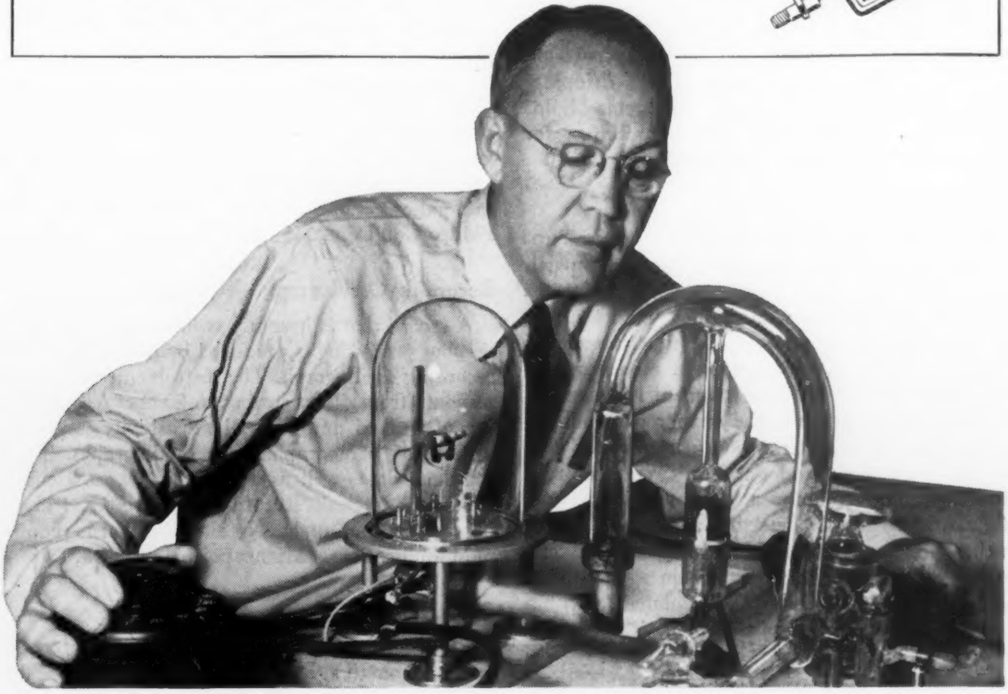
BUILDERS OF POWER FOR OUTER SPACE

New technique shapes future of transistors...
LEADS TO THREE MAJOR INVENTIONS





Calvin S. Fuller, Ph.D. in Physical Chemistry from the University of Chicago, is a pioneer in development of the diffusion technique. Here he controls a heating current through a strip of silicon while diffusing into its surface a film of aluminum less than 1/50th of a hair's breadth in thickness.

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Bell Laboratories scientists developed an efficient new way to produce such layers. They expose the metal to a hot gas containing the impurity. Atoms bombard the surface and—through a process known as "diffusion"—force their way into the metal to form a microscopic film which can be controlled in thickness to a few millionths of an inch.

The diffusion technique opened the way to three major Bell Laboratories inventions in the semiconductor field: the Bell Solar Battery, Silicon Power Rectifier and the Diffused Base Transistor. Right now the technique is providing a key to many other developments of great promise for telephony. It is another example of how Bell Labs works to improve telephony through fundamental research in materials.

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WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

Science and Technology

All inquiries concerning items listed here should be addressed to The Scientific Monthly, *Room 604, 11 W. 42 St., New York 36, N.Y. Include the name(s) of the manufacturer(s) and the department number(s).*

Paraffin Oven

A new paraffin oven that provides necessary conditions for infiltration, imbedding, spreading, and drying can be used for fine cytological and larger histological specimens. The oven is heated by two 25-w carbon-filament bulbs that are controlled by a taper-wound rheostat. A removable compartment collects drippings from transfer pipettes, and a circular top opening holds a 100-ml beaker for additional melted paraffin or for filtering paraffin. (Will Corp., Dept. M36)

Chromatograph

A vapor-phase chromatograph that can use microsamples and operate with adsorption, gas-liquid partition, and reaction columns handles a variety of compounds, including liquids with boiling points up to 325°C. The chromatograph will separate isomers of close boiling points and components in mixtures with wide boiling-point ranges. The instrument consists of a control unit and an analyzer, the former containing a power input and distribution system, a system for controlling carrier-gas flow, and detector circuit controls. A chromatographic column, a thermostatically controlled heating system, a detector, and a system for introducing the sample constitute the analyzer. The temperature of the analyzer is adjustable in a continuous range of from 60° to 250°C and is regulated to within 0.5°C. An internal sample valve, which is heated to the temperature of the analyzer, controls the size of gas samples to within ± 0.5 percent. (Consolidated Electrodynamics Corp., Dept. M37)

Radioactivity Monitor

A new monitor with fixed or moving filter automatically measures and records airborne radioactivity and warns by light and bell when preset limits are exceeded. The mobile unit will operate unattended for 7 to 10 days, and it can follow either short-term, high-level radioactivity or more slowly changing, low-level radioactivity. A flexible collecting and counting arrangement is provided for immediate continuous counting, delayed continuous counting, immediate step-wise counting, or delayed step-wise counting. Features include a positive-displacement pump, count-rate meter, variable-speed chart recorder, and a lead counting chamber 2 in. thick. (Nuclear Measurements Corp., Dept. M52)

Polarizing Spectrometer

The Quantum ellipsometer is a polarizing spectrometer that can be used to measure directly the thickness of films that can be deposited on suitable substrates in thicknesses in the range between molecular dimensions and many hundred angstroms. Both visual and photometric readings are presented. (Quantum, Inc., Dept. M106)

Gas Liquefier

Approximately 5 qt of liquid air per hour can be produced with a new gas liquefier that uses helium as a refrigerant. The air or other gas to be liquefied enters a chamber surrounding the cylinder at normal atmospheric pressure and condenses on the cold surface of the head until the quantity is large enough to be run off. Temperatures in the neighborhood of −200°C can be produced. The machine measures 37 by 20 by 34 in. and weighs 660 lb. It requires a 220-v, three-phase electric circuit suitable for a 10-hp load, as well as 3 to 4 gal of cooling water per minute. (North American Philips Co., Dept. M61)

Recording Oscillograph

A record that is instantly visible, readable, and usable without processing is produced by the Visicorder, a new recording oscillograph. The instrument has a frequency response from direct current to 2000 cy/sec without the use of peaked amplifiers; its sensitivity is comparable to that of photographic-type oscillographs. There are six channels as well as two timing traces. Deflection is 6 in. peak to peak. Record speeds are 0.2, 1, 5, and 25 in. per sec, min, or hr. No amplification is required for most applications. (Minneapolis Honeywell, Dept. M62)

Proportioning Pump

Eight different liquids or gases can be pumped singly or in combination with a new proportioning pump. Materials to be pumped enter at one end of a bank of tygon tubes that are mounted parallel to one another. An endless chain-roller mechanism pumps the materials to the other end in a virtually constant flow. Volume of delivery can be governed by varying the inside diameter of the tubes, by selecting various pump speeds, and by using a combination of tubes of different size. The pump encompasses a range from ultramicro to macro volumes. (Technicon Chromatography Corp., Dept. M65)

Spectrum Analyzer

Complex electric waveforms within a specified frequency range between 500 cy/sec and 20 kcy/sec can be analyzed with a new spectrum analyzer. The instrument provides a graphic record of the frequencies included in the waveform and of the amplitude of each. Waveforms may be either continuous or discontinuous, and the analysis is performed over successive 10-sec periods. The following types of analysis may be selected: (i) integrated volt-seconds per epic period for each of the component frequency bands; (ii) peak voltage of each of the component frequencies per epic interval; (iii) average voltage in any one of the bands; and (iv) peak voltage in any one of the bands. (Edin Co., Inc., Dept. M102)

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Cover: Icing Research Tunnel

[*Courtesy Lockheed Aircraft Corporation, Burbank, California, see page 83*]

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THE
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FEBRUARY 1957

Solar Energy on Clear and Cloudy Days

SIGMUND FRITZ

Dr. Fritz is in charge of research in solar radiation at the U.S. Weather Bureau, where he has worked almost continuously since 1937. He was trained at Brooklyn College and Massachusetts Institute of Technology. This article is based on a paper presented before the Conference on Solar Energy—the Scientific Basis that was held 31 October–1 November 1955 at the University of Arizona.

THE average amount of solar energy that reaches the outer limits of the earth's atmosphere is known within a few percent. On a surface perpendicular to the sun's rays, it is about 2 langleys per minute or about 440 British thermal units per square foot, per hour [1 langley (ly) = 1 gram-calorie per square centimeter]. On the average for the whole earth, a unit horizontal surface outside the atmosphere will receive one-half of this power during daylight hours. But even this amount of power is not available at the earth's surface because of the reflections and absorptions of the intervening atmosphere. About 35 percent of the energy intercepted by the planet earth is immediately reflected back into space (*1*). Another 19 percent is absorbed by the clear and cloudy atmosphere (*2*). Thus, only about 46 percent of the extraterrestrial energy reaches the earth's surface.

The values mentioned are averages for the whole solar spectrum and for the whole earth. However, these reflections and absorptions are not uniform for all wavelengths in the spectrum. In addition, important variations from these averages are introduced by astronomical considerations, such as latitude and season, and by atmospheric inhomogeneities, such as clouds. It is the purpose of this article to examine the principal absorptions and scatterings that solar energy undergoes in its course through our atmosphere and to discuss briefly the spectral, geographic, and seasonal distribution of the energy that reaches the earth's surface.

Atmospheric Effects on Extraterrestrial Energy

Let us begin with the energy that reaches the outer limits of our atmosphere. The solar constant is the energy received in 1 minute by an area of 1 square centimeter that is placed perpendicular to the sun's rays outside the earth's atmosphere at the mean distance of the earth from the sun. This energy is distributed spectrally as shown in Fig. 1 (*3*). The fraction of the total energy that lies below a given wavelength is also shown. For example, the energy in the ultraviolet below the wavelength 0.4 micron comprises about 9 percent of the total incident energy, the energy in the visible region (which contains the peak at 0.46 micron) comprises 41 percent, and that in the infrared beyond 0.72 micron contains about 50 percent. The extraterrestrial spectrum, according to Moon (*4*), is also shown. This is much the same as Johnson's spectrum (*3*), but Moon's values are lower in the ultraviolet.

This, then, is the solar spectrum that we must trace down through the atmosphere. X-rays and

other very short-wavelength radiations are absorbed very high in the ionosphere by oxygen, nitrogen, and other atmospheric constituents. Somewhat longer wavelengths are absorbed by ozone. There is rarely more than 0.4 centimeters (S.T.P.) of ozone in a vertical column of the atmosphere, concentrated mainly at elevations between 15 and 35 kilometers; yet the absorption coefficients of ozone are so large that the spectrum of solar energy at the ground is cut off below 0.29 micron.

Therefore, from the viewpoint of utilization of solar energy near the ground, we need to focus our attention only on wavelengths longer than 0.29 micron. As the remaining solar energy proceeds through our atmosphere, it undergoes two principal variations. It may be scattered, or it may be absorbed.

Scattering may be accomplished by molecules, by dust or other atmospheric impurities, and by cloud particles. Small amounts of many substances absorb solar energy, but the principal absorbing mediums are ozone, water vapor, and cloud particles.

The simplest case to consider is the cloudless atmosphere. The transmissivity T of a parallel monochromatic beam of wavelength λ through the atmosphere is given by the equation

$$T_\lambda = \frac{I_\lambda}{I_{o\lambda}} = e^{-[s_a + (s_d d + s_w w)]m} \cdot e^{-[a_o(O_3) + a_w w + a_d d]m} \quad (1)$$
$$= (\text{scattering factor}) \cdot (\text{absorption factor})$$

Both factors are to be considered at a single wavelength λ.

Scattering

The main scattering agents in the atmosphere are (i) air molecules that, for the vertical atmosphere, have a scattering coefficient s_a; (ii) the amount of dust d in the vertical, with a scattering coefficient s_d; and (iii) perhaps the amount of water vapor w in the vertical, with a scattering coefficient s_w. In Eq. 1, m is the optical "air mass" or the path length through the atmosphere, the vertical path being considered unity at sea level; I_λ is the intensity of the parallel solar beam at the ground; $I_{o\lambda}$ is the intensity outside the atmosphere.

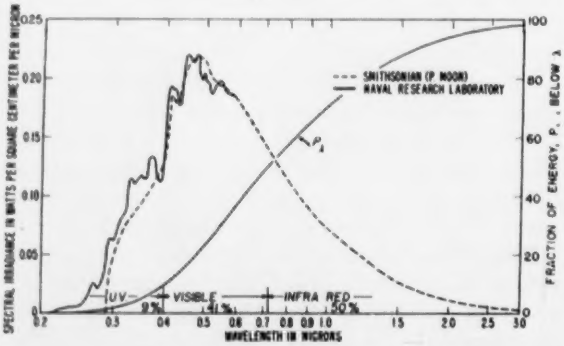

Fig. 1. Extraterrestrial solar spectrum (*3*). Curve P_λ shows the fraction of the total solar energy below wavelength λ. The limits of the ultraviolet, visible, and infrared regions are approximate.

Air molecules are very small by comparison with the wavelengths that we are considering. Scattering by molecules, therefore, occurs in accordance with Rayleigh's theory. Rayleigh showed that, in this case, the scattering coefficient s_a would vary approximately as λ^{-4}, and this has been amply verified experimentally. Thus,

$$s_{a\lambda} = c_{a\lambda}\lambda^{-4} \quad (2)$$

where $c_{a\lambda}$ is nearly a constant at sea level but varies slightly with λ. For a pure, dry atmosphere, Penndorf (*5*) has recently computed the transmissivity $T_{a\lambda}$ through the vertical atmosphere; his results are given in Fig. 2. Here $T_{a\lambda} \approx 30$ percent for $\lambda = 0.3$ micron, and T_a increases with wavelength until it is more than 96 percent at $\lambda = 0.7$ micron, near the beginning of the infrared. Thus, for the ultraviolet near 0.3 micron, we do not expect very much energy to reach the surface because of scattering alone. But, as we shall see, ozone absorption reduces that energy to even smaller values. Moon adopted $c_{a\lambda} = 0.00875$ for a surface pressure of 760 millimeters. His transmissivity values are close to those of Penndorf.

Scattering by particles that are larger than air molecules is much more complicated. Whereas the number of air molecules above a given point is nearly constant, the number of nonmolecular particles can vary from only a few per cubic centimeter to thousands per cubic centimeter. The number measured at the ground gives only a rough indication of the total effect, for the number per cubic centimeter will vary with height. Moreover, the scattering effect, or the effective scattering area K of a single spherical particle depends on the radius r of the particle, *and* on the wavelength of the light that is being scattered (*6*); the parameter that determines K is $2\pi r/\lambda$.

Given all the required information, it is theoretically possible to estimate the total influence of these particles on the transmission of the direct solar beam, but in a particular case the required information regarding the number of particles, their size distribution, and their composition will not be known. Moreover, the separate effects of absorption and scattering are difficult to separate for dust. As a compromise, Ångström (*7*) found that the

scattering coefficient of the conglomeration of particles in the atmosphere may be approximated (*8*) in a form similar to that of the Rayleigh scattering coefficient, namely

$$s_d = c_d \lambda^{-f} \qquad (3)$$

where f is an exponent the value of which depends on the "average" size of the particles, and where c_d depends on the number of particles. Equation 3 includes also the effect of absorption by dust. According to Fowle (*9*), there exists a scattering coefficient which varies with the water-vapor content of the atmosphere. Fowle suggested that this was caused by a coagulation of several water-vapor molecules. However, it is known that many particles in the atmosphere will increase in size under suitable conditions of humidity by the accumulation of water vapor. Thus, as Ångström suggested, Fowle's observed water-vapor dependence may really depend also on the number and size of the dust particles present. At any rate, relationships of the form of Eq. 3 can approximate "water-vapor scattering" and "dust scattering." Moon has preferred Fowle's method of treating the two scattering mediums separately.

On the basis of his analysis of Fowle's data, Moon has adopted the values $s_{w\lambda} = 0.00865\ \lambda^{-2}$ for w in centimeters of water vapor and $s_d = 0.0102\ \lambda^{-0.75}$ for d in hundreds of particles. The variation of the scattering coefficients with λ is thus much less for particles than it is for molecules. The influence of scattering by dust is ordinarily less than that by air, except in polluted city areas. By the use of s_a, s_w, and s_d with the numerical constants, it is now possible to compute the scattering factor of Eq. 1 for any wavelength to a fair approximation when d and w are known or can be estimated.

Absorption; Ozone; Water Vapor

Ozone absorption in the atmosphere also plays an important role in modifying the solar energy before it reaches the ground. Ozone absorbs very strongly at 0.25 micron, and its absorption coefficient drops gradually as λ increases (*10, 11*).

In middle latitudes, 0.25 centimeter of ozone (S.T.P.) is a representative value. The transmission through 0.25 centimeter (on the basis of data in List, *10*) is shown in Fig. 2, where we see that even by itself ozone would transmit less than 0.01 percent at 0.29 micron and about 50 percent at 0.31 micron, while the transmissivity approaches unity near $\lambda = 0.35$ micron. Ozone also absorbs weakly near 0.6 micron in the Chappuis band, where the transmissivity exceeds 95 percent at all wavelengths.

In the infrared regions of the solar spectrum,

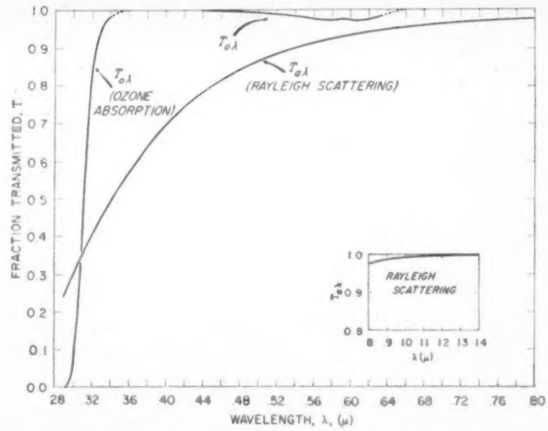

Fig. 2. Fraction of energy transmitted through the vertical atmosphere. Curve $T_{a\lambda}$ shows only the effect of Rayleigh scattering by the air molecules (data from Penndorf, *5*). Curve $T_{o\lambda}$ shows only the effect of passage through 0.25 centimeter of ozone (absorption coefficient from List, *10*).

absorption by water vapor plays an important role. The absorption spectrum will depend somewhat on the instrument used to measure it. On the basis of data available, a summary of the absorption coefficients of both water vapor and liquid water was prepared by Albrecht (*12*). He found large oscillations in the water-vapor absorption coefficients as the wavelength varies. An interesting point is that the coefficient for the vapor often exceeds that of the liquid in the region below 1.5 microns.

With these absorption coefficients, we now have available all that is needed to compute the solar energy reaching the ground as a direct beam on cloudless days if the amount of ozone, water vapor, and dust is given.

By using coefficients similar to the ones presented here, Moon (*4*) has computed the spectral distribution of the energy that reaches sea level as a direct solar beam on cloudless days when $w = 2$ centimeters of precipitable water vapor, $d = 300$ particles per cubic centimeter, and ozone $= 0.28$ centimeter. Moon's curves (*13*) for $m = 1$ to 5 are given in Fig. 3, which shows the energy that reaches the ground as a direct beam as a function of λ. Here we note the large vertical separation of the curves for the shorter wavelength, indicating the large influence of Rayleigh scattering and of ozone absorption as the sun passes through longer and longer paths. As we progress into the infrared, the absorption bands of water vapor become quite pronounced, but in the regions where water vapor does not absorb, depletion of the beam is rather small, indicating the small influence of dust. In the stronger water-vapor bands, practically no

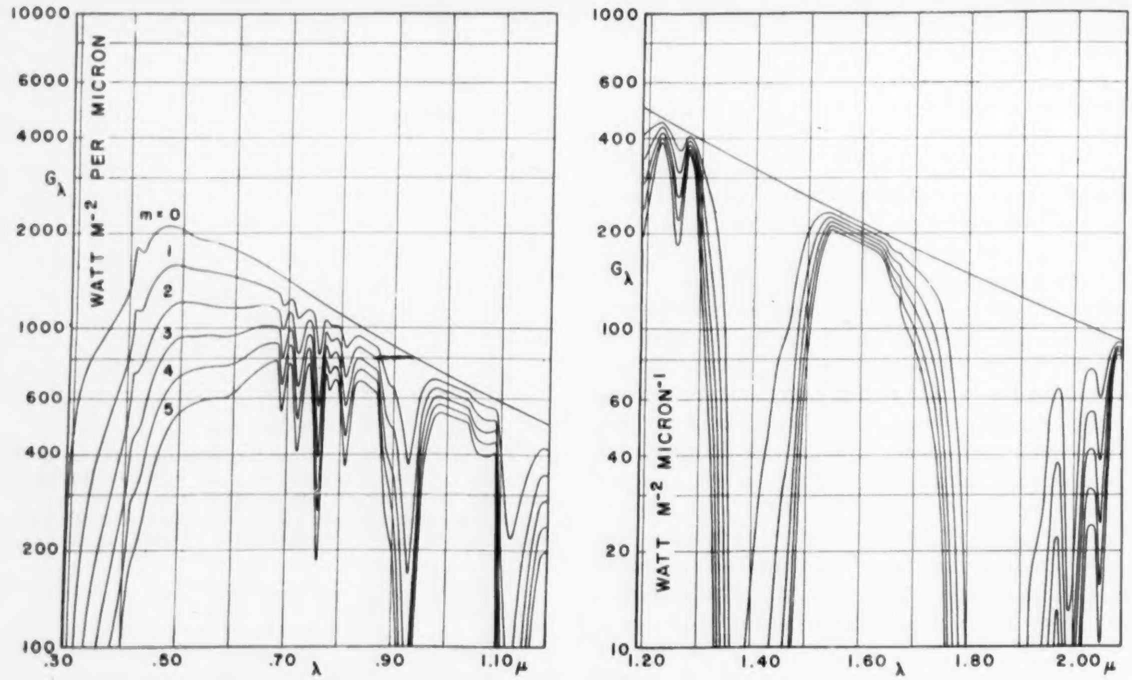

Fig. 3. The solar spectral-energy distribution on a surface perpendicular to the direct beam (*4*). The curve for $m = 0$ is Moon's extraterrestrial spectrum; the curve for $m = 1$ is the spectrum after passage through the vertical atmosphere; the curve for $m = 2$ is the spectrum after passage through an optical path twice the vertical atmosphere, and so on. Surface air pressure, 760 millimeters; amount of water vapor, 20 millimeters (precipitable); 300 dust particles per cubic centimeter; ozone, 2.8 millimeters.

energy reaches the ground at all, especially for large optical air masses. The areas under the curves give the total energy in the direct beam. These agree fairly well with measured values at Washington, D.C. Brooks (*14*) has computed the intensity of the direct beam in a somewhat different manner.

Cloudless Sky Radiation

We have just seen how to estimate the energy in the direct solar beam on a cloudless day. We have also noted that some of the depleted energy is scattered. A portion of the scattered energy will return to space, but some of it also reaches the ground as skylight. In a perfectly pure atmosphere, relatively little infrared radiation is scattered. On the other hand, an appreciable fraction of the short-wave energy is scattered.

Of the energy that is scattered by a particle, the fraction scattered downward in a single encounter will depend strongly on the scattering pattern of the particles. Air molecules, scattering in accord with Rayleigh's theory, scatter energy symmetrically about the forward direction, with a maximum forward and backward and a minimum at 90° from the forward direction.

Larger particles, on the other hand, usually scatter more energy forward than they scatter backward; this effect increases as the particle size increases. Thus, when large particles are present, additional energy will be scattered from the direct beam, but we should expect a greater fraction of the scattered energy to reach the earth's surface as skylight. Multiple scattering will complicate this simple picture even more.

To get an idea of the role of the larger particles, we can compare pure Rayleigh scattering with actual measurements of the spectrum of the sky. Deirmendjian and Sekera (*15*) have computed the spectral energy distribution to be expected from the sky at the ground on a horizontal surface. Luckiesh (*16*) has measured the actual sky radiation in Cleveland on a clear summer day near noon. In Fig. 4 we see that Rayleigh scattering requires more sky radiation than that observed at short wavelengths and less than that observed at wavelengths larger than 0.35 micron. The larger observed amount at longer wavelengths is undoubtedly the result of the presence of nonmolecular particles. The low observed energy at short wavelengths is, in part at least, the result of ozone absorption.

Table 1. Reflection of sunlight to space (percentage).

	Ultraviolet	Visible	Infrared	Total
Earth	0.1	1.1	1.1	2.3
Clouds	2.6	11.3	10.2	23.3
Atmosphere	2.6	5.2	1.3	9.1
Totals	4.5	17.6	12.6	34.7
Albedos	50	39	27	35

The total energy that reaches the ground from the sky varies with solar elevation. For an average clear sky in Washington, D.C., the diffuse sky radiation on a horizontal surface (*17*) is about 16 percent of the total when the sun is high and about 37 percent of the total when the solar elevation is about 10°.

Clouds

The sky is, of course, not always cloudless. In certain places during some seasons, overcast skies are more prevalent than clear skies. We should therefore investigate the influence of clouds on solar energy. Looking at the whole earth again, we have stated that the planet reflects about 35 percent of the intercepted energy back into space (*18*). By far the largest portion of this is reflected by clouds. A summary (*1*) of the reflections by the various constituents of the atmosphere is given in Table 1. Here we see that, in total sunlight, the clouds reflect to space about 23 percent of the incident energy, while the ground and atmosphere reflect only 2 percent and 9 percent, respectively. The albedo or reflectance of a "surface" is the

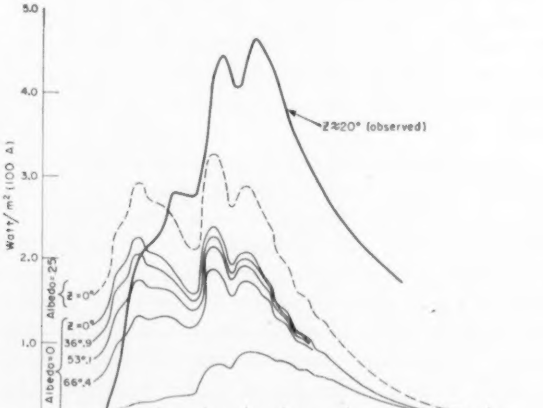

Fig. 4. The radiation from the sky alone on the basis of pure Rayleigh scattering. Albedo refers to reflectance of the earth's surface. Curves for various sun-zenith distances Z are shown (*15*). Curve marked "observed" is for Cleveland on a clear day in midsummer near noon (*16*).

amount of energy reflected outward expressed as a fraction of the energy incident on the surface. The surface may be the planet earth, a cloud, the ground, and so on. It may be of interest to note that in ultraviolet light, the albedo of the whole earth is about 50 percent, for visible light it is 39 percent, and for infrared light it is 27 percent. On the basis of this study, it was estimated that the average albedo of clouds is about 50 percent, and observations show that the albedo of clouds may vary from a few percent to more than 90 percent.

Let us take a closer look at the details of scattering of light by clouds. Clouds are made up of liquid and solid particles that are in general much larger than the wavelengths of sunlight under consideration. The "average" droplet size, for example, in a liquid water cloud is about 10 microns; this compares with $\lambda = 0.5$ micron in visible light, near the peak of solar intensity. In the absence of absorptions, this permits us to assume that the scattering of the light is nearly independent of λ. Moreover, the intensity of scattered energy caused only by reflection and refraction by a large water drop has been given by Wiener and has been discussed by Fritz (*19*; see also *20*). The energy is scattered predominantly in the forward direction; nevertheless, a small portion is scattered in all other directions. We can picture the scattered energy as made up of a portion scattered equally around the drop in *all* directions and a remaining forward-scattered portion. In addition, there will be the remainder of the direct parallel solar beam that has not encountered drops at all. We can thus picture a direct beam and a forward-scattered beam; each of these beams will collide with drops and will generate diffuse, nearly isotropic energy around the individual drops in the cloud.

To simplify the problem further, let us consider that the cloud of spherical water particles is of infinite size in all horizontal directions but of finite thickness. Let us divide the cloud into layers so thin that when the direct beam intercepts a drop, the intercepted light is scattered only once in *that* layer; the light will, of course, be scattered again in other layers. It can be shown that, in layers of thickness $L/4$, approximately one scatter occurs. Here L is the mean free path of the light through the cloud and is given by the equation

$$L = \frac{1}{\Sigma N \pi r^2}$$

The summation is over drop radius r, and N is the number of drops per cubic centimeter.

If we now take into account the three-dimensional scatter by the particles, we can compute where in the cloud the diffuse energy is generated.

The diffuse energy generated increases rapidly to a maximum about 1½ mean free-path lengths below the cloud top and then decreases gradually. In the absence of absorption, this generated diffuse energy must diffuse through the cloud. By using a simple, steady-state diffusion equation and by imposing boundary conditions determined by sky radiation on top and by the ground albedo below, we can compute the amount of energy that will escape through the top of the cloud during the diffusion process; we can, in this way, also compute what fraction is transmitted by the cloud. The results of such computations with ground albedo $a = 0$ are shown in Fig. 5. Here the cloud thickness is given in terms of the nondimensional parameter h/L, and h is the geometric cloud thickness. Each

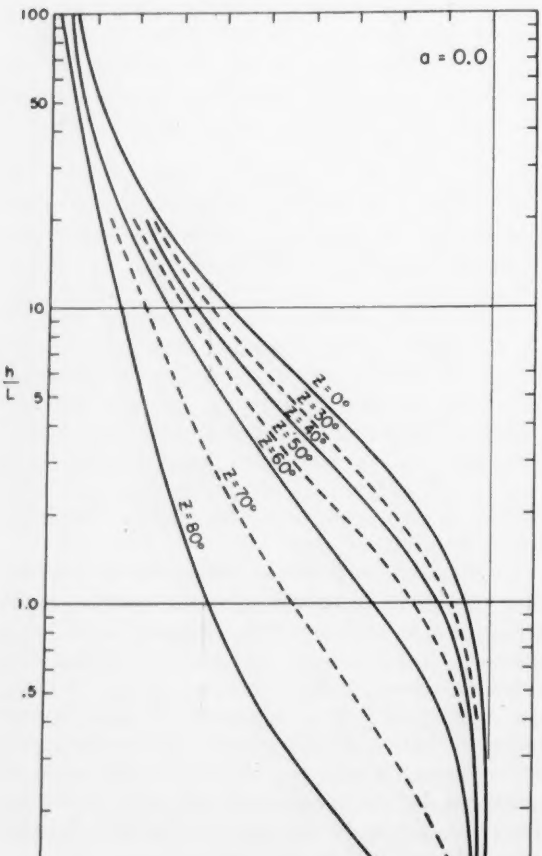

Fig. 5. Transmittance through overcast cloud—that is, fraction of direct-beam energy incident on a horizontal cloud top which is transmitted to ground (*20*). The ordinate is cloud's optical thickness; h is the geometric thickness, L is the mean free path. The sun's zenith distance Z is shown on curves; surface albedo $a = 0$.

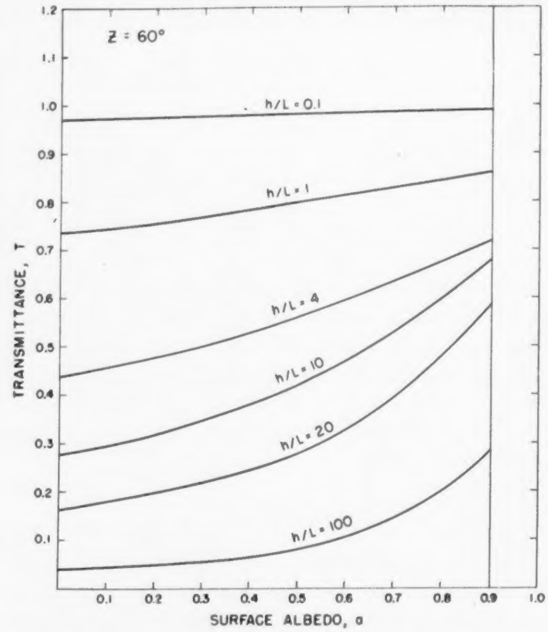

Fig. 6. Transmittance through overcast cloud as a function of surface albedo a for various optical thicknesses, h/L. Sun's zenith distance $Z = 60°$. (For old snow, $a \approx 0.5$; for fresh, cold snow, $a \approx 0.9$)

curve applies for the sun's zenith distance Z that is shown. As we would expect, the transmittance decreases as the cloud thickness increases. Another result is that the transmittance of the cloud varies markedly with Z, especially in the region $h/L \approx 1$, which is often characteristic of stratus clouds. Thus, even with a given fixed cloud, we should expect the fraction of energy transmitted by the cloud at noon to be much greater than the fraction transmitted near sunrise for relatively thin clouds. For very thick clouds, the transmittance in visible light approaches zero and becomes independent of Z.

The reflectance of the ground will have an important bearing on the amount of energy that an instrument below the cloud will receive. This is illustrated for $Z = 60°$ in Fig. 6. The surface albedo a is shown as the abscissa, and the cloud transmittance is given as the ordinate. For very thin clouds, the transmittance increases slowly with a, but for thick clouds the transmittance increases quite rapidly with a. For $h/L = 20$, for example, the transmittance through a cloud over fresh snow ($a = 0.9$) is about 3.5 times greater than it is for a cloud over a forest ($a < 0.1$). The importance of snow is the result of numerous interreflections between the cloud and the underlying snow surface.

Absorption in Clouds

The discussion about clouds has so far been referred to visible light, which is practically not absorbed by clouds. However, as we have already seen, about half the solar energy is in the infrared region, where important absorptions occur. The theoretical development of scattering with absorptions present is much more complicated because now, in addition to the scattering process just described, we have two different absorbing media, liquid water and water vapor, which occur in different amounts, and each of these has a different absorption coefficient that varies radically with wavelength. Thus, we must now consider the diffusion process wavelength by wavelength.

We proceed as in the case of nonabsorption, except that, in each scattering layer, we must now take into account the absorption by water and water vapor. Finally, when considering the diffuse-generated energy, we must use a diffusion equation with an absorption term. The amount of energy absorbed by the cloud at any wavelength will depend, among other things, on the energy incident on the cloud.

At first we consider a very thick cloud the top of which is so high that we may assume that extraterrestrial energy falls on it. The absorption in relative units in such a cloud is given in curve 1 of Fig. 7 (*21*). In this cloud, it was assumed that the water-vapor content was 1 gram per cubic meter, the liquid water content was 0.1 gram per cubic meter, and the effective scattering radius of the drops was 15 microns.

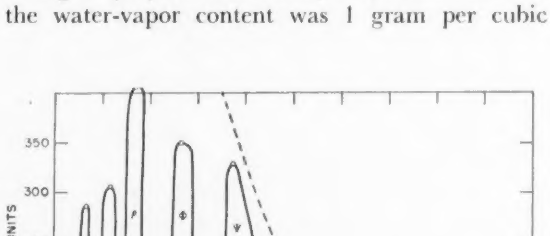

Fig. 7. Relative amount of energy absorbed in an infinitely thick cloud as a function of wavelength. Curve 1 assumes that the extraterrestrial solar spectrum is incident on cloud top. Curve 2 assumes that the solar beam has passed through 2 centimeters of precipitable water vapor before reaching the cloud top. Cloud parameters: liquid-water content, 0.1 gram per cubic meter; water-vapor content, 1.0 gram per cubic meter; effective drop radius, 15 microns (*21*).

The pronounced water-vapor absorption bands are clearly evident. The absorption in the troughs of the absorption bands is due mainly to the absorption by liquid water, and it is clear that the vapor is often at least as important an absorbing medium as the liquid. The total absorption in the cloud is obtained by integrating under the curve. The fraction absorbed was 23 percent of the energy incident on the cloud top; but clouds with different liquid and vapor contents will absorb different amounts.

If an appreciable amount of water vapor overlies the cloud, little energy will reach the cloud top in the water-vapor bands. For a thick cloud with 2 centimeters of precipitable water vapor above it, the absorption is given by curve 2 in Fig. 7. Here we see that the absorption in the cloud is substantially reduced, especially in the centers of the water-vapor bands, because the energy in those bands has been absorbed by the water vapor above the cloud. All of this means that we should expect to find only very small fractions of solar energy in the water-vapor absorption bands transmitted to the ground through clouds.

Of course, the thickness of the cloud will influence the amount of absorption. In Fig. 8, the absorption, reflection, and transmission through the cloud is given as a function of the cloud thickness in terms of h/L. The liquid and vapor contents and the drop sizes are the same as they are in Fig. 7. The absorption increases rapidly and then more slowly approaches the maximum asymptotically. The transmission is high for the thin cloud and approaches zero as the cloud becomes very thick.

The spectrum of the overcast sky as seen from below has been measured only on a few occasions, and these measurements have been confined mainly to visible light. It turns out that the visible spectrum of the overcast sky is quite similar to the visible spectrum from the sun and clear sky combined (*22*).

And this is what we should expect. The energy that irradiates the top of a cloud is a combination of the direct solar beam and of the skylight that has been scattered down by air molecules above the cloud. This incident radiation will not be identical with the radiation from the cloudless sky at the ground, but it will be similar. Since the cloud particles are generally large with respect to the wavelength in visible light, they scatter light more or less independently of the wavelength. Consequently, although the energy that penetrates to the ground

will be much reduced in magnitude, its spectral distribution in visible light will be rather similar to the total visible energy that falls on the cloud and also to the spectral distribution on cloudless days. The spectral albedo of the ground will also have some influence on the spectrum of the overcast sky (*23*) because the energy reflected upward by the ground is then further reflected downward by the cloud; and a strong reflectance by the ground at a particular wavelength will also enhance the downcoming energy at that wavelength.

In the infrared region, there do not appear to be any measurements. We should expect that the absorptions by both liquid water and water vapor will modify the incident energy markedly, and in particular the intense water-vapor bands will decrease the solar energy to practically zero beneath moderately thick, warm clouds.

Solar Radiation Available at the Ground

To utilize solar energy at the ground, we need to compute the amount of energy reaching the ground. For cloudless skies, especially without much pollution, we have already seen that fairly good estimates can be made. But for overcast skies, we would have to know not only the cloud thickness h but also the mean free path L. In any particular case L is sure to be unavailable, for it involves the unobserved drop-size distribution and liquid-water content of clouds. On the contrary, it is easier to measure the solar radiation in order to estimate h/L than the other way around. For isolated clouds, such as occur with partly cloudy skies, the precise influence of clouds is even harder to estimate.

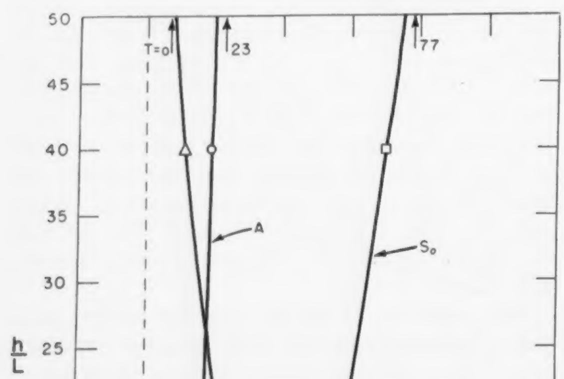

Fig. 8. Energy absorbed (A), transmitted (T), and reflected (S_0) as a function of cloud thickness h/L. Cloud parameters are the same as those in Fig. 7.

Faced with this impasse, we have at least two choices. One is to measure the solar energy wherever and whenever we want to know its value. This might prove to be a fairly expensive approach. The other alternative is to measure the radiation in a few places. These measurements can then be correlated with parameters that are observed in many places. Such parameters include cloud amount C or number of minutes of sunshine. The statistical relationships thus obtained can perhaps be used where estimates of solar energy are needed.

Many meteorological services have organized solar-radiation networks consisting of one or more stations. In the United States we have a network of about 75 cooperative and Weather Bureau stations. At each of these stations, solar radiation is measured on a horizontal surface. In addition, there are five stations that measure radiation perpendicular to the sun when the sun is not obscured by clouds. And finally, at Blue Hill, Massachusetts, the Weather Bureau measures radiation on vertical surfaces oriented at the cardinal compass points and also diffuse radiation from the clear and cloudy sky on a horizontal surface. Eppley thermopile-type receivers are used with potentiometric recorders to obtain the data.

Networks also exist in several other countries, where much the same types of measurements are made. In some cases, spectral measurements with filters are available, and photocells may be used to measure radiation in the visible or ultraviolet portions of the spectrum. For example, in Washington, D.C., we record illumination with a photocell and viscor-filter combination.

Meteorological networks also observe clouds in more or less detail at a great many stations, giving generally the cloud type or amount or both. At many stations, the number of minutes of sunshine is measured, which is often translated into a percentage S of the maximum possible minutes of sunshine.

With the aid of simultaneous observations of solar radiation and the number of tenths of cloudiness C or percentage of sunshine S, numerous statistical relationships have been derived.

It is customary to assume the linear relationships

$$Q = Q_0(a + bS) \quad (4)$$

or

$$Q = Q_0[a' + b'(1 - C)] \quad (5)$$

The percentage of sunshine S varies from 0 to 100 percent, and C varies from 0 to 10 tenths. Here Q is the radiation that reaches a horizontal surface on an average day; Q_0 is the corresponding radiation for cloudless conditions; and a, b, a', and b' are empirical constants.

A discussion including typical values of a and b has been published (*24*). If measured average *monthly* data are put into Eqs. 4 and 5, a linear relationship is generally justified. This is true because the range of S or C in monthly averages usually covers only a narrow range—for example, the range of S will cover a small portion of the possible values from 0 to 100, because a month usually includes clear, partly cloudy, and cloudy days.

If one observes daily values, then Eq. 5 does not give a good estimate of Q because the observed relationship is not linear. On overcast days, with $C = 1.0$, average clouds appear to be relatively much more dense than on days with intermediate values of C. But if one uses S, the linear relationship is more nearly fulfilled. This latter point probably results from the fact that cirriform clouds are ignored by the sunshine recorder; days with cirriform clouds are treated like clear days. Cirriform clouds reduce the solar energy by relatively small amounts. As a consequence, only the optically more dense clouds are included in the sunshine measurements.

Of course, where S is not measured, one may have to resort to observations of C but recognize that, with constants which give correct values when $C = 0$ and $C = 1.0$, values of Q when $C \approx 0.5$ will be underestimated appreciably. If suitable data are available, it would be best to use C for relatively dense "opaque" clouds only. Finally, large scatter about the average is to be expected for individual days, regardless of whether C or S is used.

Nonhorizontal Surfaces

So far we have discussed the measurements on horizontal surfaces. For some purposes it is desirable to know the energy on vertical or tilted surfaces. Again, for cloudless days, it is relatively easy to estimate the solar energy on any plane surface.

But when cloudiness is present, the computations become difficult because h/L is not known and because cloud-type data by amounts are not readily available. So again we must resort to empirical relationships. The most widely measured type of solar radiation is that from the sun and sky on a horizontal surface. It therefore seems logical, with limited funds, to measure the solar radiation on other surfaces at a few places and to relate the new measurements to those on a horizontal surface. The hope is that, after enough data have been accumulated, general relationships will be found so that computations can be made at other places where the nonhorizontal surface measurements are not available. Several summaries of such data are listed in a bibliography of papers by I. F. Hand (*25*).

In the United States, the main station for these experimental studies has been at Blue Hill Observatory near Boston, Massachusetts. The results so far obtained are, strictly speaking, applicable only for that station, but by relating these results to a cloudiness index such as the percentage of sunshine and to the elevation and azimuth of the sun, it may be possible to generalize enough to make the results applicable to other areas, especially in those months when the ground is free of a snow cover. This has not yet been done.

Geographic and Seasonal Variation

For many purposes it is desirable to know the amount of solar energy that reaches a horizontal surface. By using some of the relationships mentioned in previous paragraphs, we can compute the radiation on a horizontal surface at any unpolluted place in the world with fairly good accuracy for cloudless days. By using the empirical statistical relationships between cloud index and radiation, we can estimate the solar radiation during any time period at any place, but with much less accuracy. Such computations have been made for cloudless days, and, where possible, they have been anchored to measured values (*26*). The average radiation in the United States for all days is shown in Fig. 9 (*27*). In December, the latitudinal variation is particularly marked and overshadows all other effects. In summer, because the day is longer in the north and the solar elevation is large at noon everywhere, the radiation is much more uniform with latitude. Therefore, cloudless areas, mountain peaks, dry areas, and nonpolluted areas appear as regions with high radiation.

Summary

We have seen that in the cloudless atmosphere our knowledge about Rayleigh scattering and absorption by ozone will permit fairly good engineering approximations of the average solar energy received at the ground on any surface at any time in almost any place, at least from the direct beam.

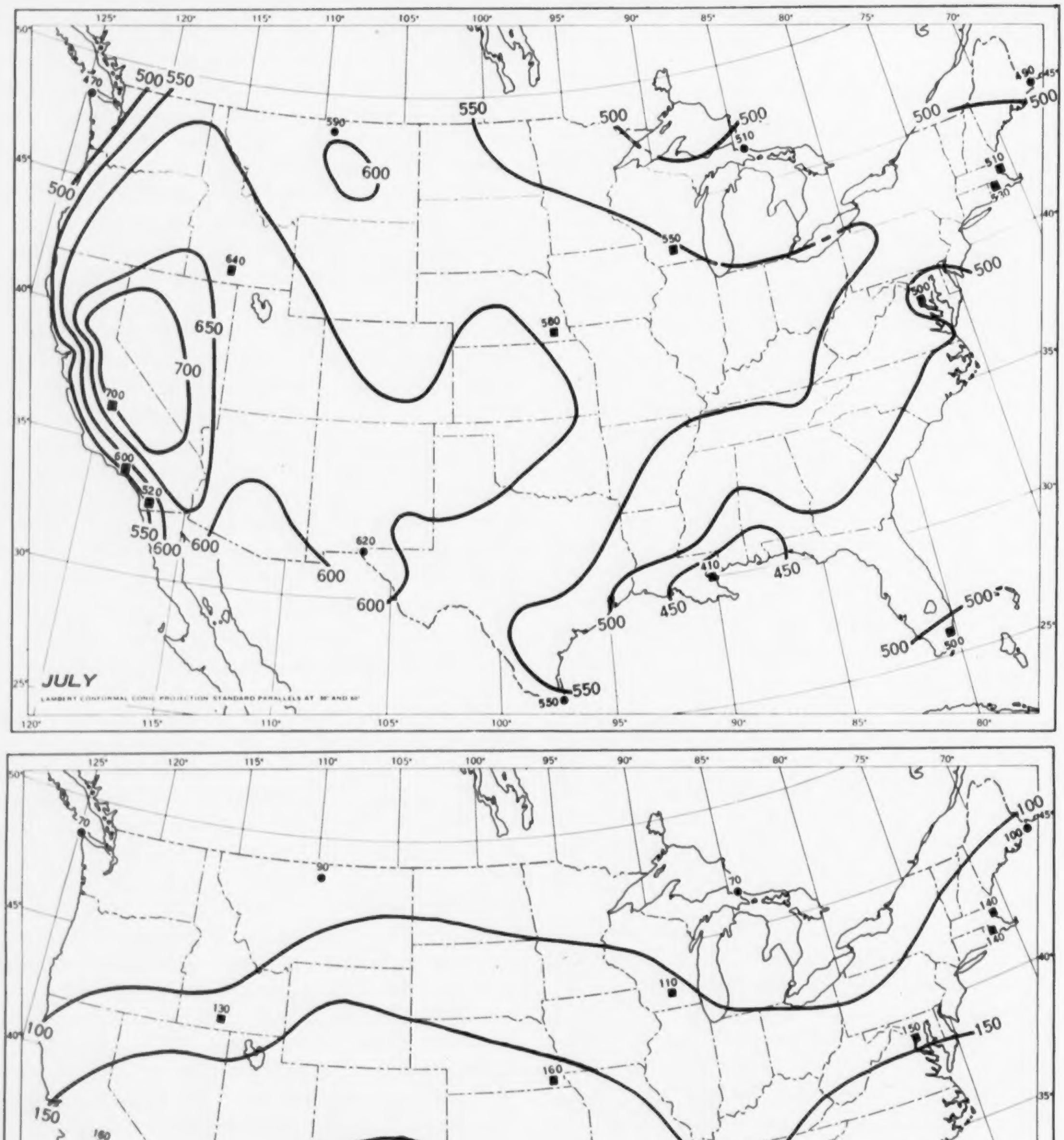

Fig. 9. Isolines of average solar radiation received on a horizontal surface in the United States during days with average cloudiness in July (top) (*27*) and in December (bottom). Units are langleys per day. To convert to British thermal units per square foot, per day, multiply by 3.69.

The introduction of "dust" and water vapor will require modifications, which can be taken into account when the amount of water vapor and dust is known. In highly polluted atmospheres, the computations will become more difficult because of our imperfect knowledge about the number, size distribution, and the scattering and absorbing properties of the polluting particles.

When we try to compute the influence of clouds, we run into difficulty because clouds are inhomogeneous, and the theory has been simplified to take account of homogeneous clouds only. Moreover, we do not, in general, know enough about the drop-size distribution and the number of drops per unit volume in a given cloud. We are forced to resort to empirical relationships between cloud amount indexes and solar radiation in an attempt to estimate how much solar radiation will reach the ground on the average at a place where radiation measurements are not available.

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Rice Culture in Spain

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THE social and economic institutions of a given agricultural community do not depend solely on the natural resources of the region in which the community is located, for natural resources may be exploited in more than one way. There is a kind of interaction between the natural resources of a region and the institutions of the people who live there. In the light of its institutions, a community may seek to change its physical environment. Such changes may in turn produce changes in the institutions of the community. As a result, sometimes rich soils support poor populations, and sometimes relatively infertile lands are inhabited by relatively prosperous people.

In two widely separated sectors of Spain, the principal crop is rice. Although both sectors grow the same crop, there are instructive differences in natural resources and in the institutions of the two communities. One sector is near Seville, a city located in the Andalusian plain of southern Spain. Until recently, this fertile land was used almost exclusively as pasture for fighting bulls. The other sector is near Valencia, which is located on the coastal plain of eastern Spain. The land in this sector has been reclaimed from deserts and from swamp land.

This article examines the communities living in these two sectors, describing the differences in social and economic institutions, and offering an account of how these differences arose (*1*). The kinds of differences considered include ownership of land, farming techniques, sources of labor, markets, and local government. For example, we find that in the Seville sector the land is divided into huge estates, called *latifundia,* while in the Valencia sector the land is broken up into small plots, called minifundia, which are owned by the people who work them. We shall see that the differences in institutions arose through the interaction of the resources of the land with the different groups of people who, in the course of Spain's history, came to occupy that land, from the Roman and later Moorish conquests to the present.

Historical Background

The history of Spain can in many respects be interpreted as a centuries-long contest between the rich and fertile farming districts of the Guadalquivir Valley and of the east coast of Spain on the one hand, and the inhospitable, semipastoral tableland of Castile on the other hand. For several centuries after the Roman conquest (149–146 B.C.) the larger part of the country was held in great estates, which were owned by Romans and worked by serfs. After the collapse of the West Roman Empire in the 5th century A.D. under the impact of the Visigoths, the status quo was simply maintained.

However, in 711, Arabic-speaking Moors crossed the Straits of Gibraltar, struck deep roots in southern and eastern Spain, and in a few years overran most of the Iberian Peninsula. The large estates of Roman times gave way to small holdings under intensive cultivation. New crops such as sugar cane, rice, cotton, alfalfa, oranges, and lemons were introduced, and an elaborate system of irrigation and drainage channels was developed wherever feasible. The industrial and commercial centers of Seville, Cordoba, and Valencia were among the richest and most civilized cities in the world.

The Moors were proverbially industrious, as expressed in the popular Castilian saying, "To work hard like a Moor." They dominated the Iberian Peninsula for almost 800 years, and only in 1492 was the last Moorish stronghold at Granada taken by the Spaniards. However, the reconquest of Andalusia by the semipastoral Spaniards of the north was immediately followed by expulsion of the Moors; irrigation channels got filled in, famines and epidemics depopulated the countryside, and by the end of the 17th century almost the whole of

this once fertile land was ranged over by herds of transhumant sheep and cattle.

The Castilian nobles saw that the easiest and most profitable use to which they could put their newly won territories would be to turn them into sheep runs. They founded the famous sheep-ranchers' guild known as the Mesta, and their transhumant sheep, moving long distances in their seasonal migrations, were by royal decree allowed to graze at will along the route. The unorganized peasants on their unfenced fields were helpless, and intensive agriculture and large-scale industry, the basis of Andalusian prosperity, became things of the past. The name of this once rich and prosperous country became a byword for misery and starvation as the Christian peasant sank to the status of "poor white" and the large estates were worked with slave labor. There seemed to be special force in the old proverb that "Castile made Spain and Castile has unmade it" (*2*). There was a vicious circle of undernourishment and epidemics in Seville. "May God deliver you from disease coming down from Castile and from starvation coming up from Andalusia!" one reads in Guzmán de Alfarache.

During the first half of the 19th century, common lands and church property were put on the market, but the peasants and poor villagers lacked the capital to buy them. Instead, the lands were acquired by enterprising landlords and local capitalists, with the result that, especially in Andalusia, great estates increased both in number and in size, and began to be worked by the *nouveaux riches,* who had a sharper eye for profit than the former feudal landlords. Most of the estates in Andalusia today were formed out of the breakup of the church and common lands a century ago, and these lands have given financial and political power to the class that has ruled Spain since that day. Unfortunately, the estates rapidly took on the worst characteristics of the neighboring vast feudal landholdings, or *latifundia,* which were established in Roman times and were reconstituted in certain sectors by the Arab rulers, and which were given intact by Ferdinand III to the feudal lords who accompanied him in his conquest of Seville, capital of one of the most fertile sectors of the peninsula, the valley of the Guadalquivir River (*3*).

The Guadalquivir River, meandering slowly on the floorlike expanse of its alluvial flood plain downstream from Seville, divides into several distributaries and forms the Isla Mayor to the west and the Isla Menor to the east. These islands, which are subject to floods downstream, are for the most part dry land in their upstream parts. They are about as nearly level as it is possible for land to be in nature. Indeed, Seville, which is 60 miles from the sea, is only 30 feet above sea level.

Carrion (*4*) pointed out that 73 per cent of the land of the Guadalquivir, thousands of acres of rich "vega," or irrigable land, is given over to the chase or to bull breeding. Chronic unemployment, with the poverty, malnutrition, and epidemics attendant on it, has for half a century made the population of Andalusia ready to follow any party —anarchosyndicalist or socialist—that promised speedy and sweeping agrarian reform. The misery of the peasantry that results from its lack of land is the basic theme in Blasco-Ibañez' novel *La Bodega.*

"Thousands of people suffer the pangs of hunger, victims of a daily wage, because they do not have land to cultivate; and the land is set aside for animals, in the vicinity of a civilized city. But the main animal in that vast plain was not the patient ox who produces meat for the consumption of man, but the savage bull for the fights in the bull ring, whose fierceness alone was the goal of the breeder, who strove only to increase it.

"The immense plain would easily support four villages where hundreds of people could make a living, but the land was for the sole use of these fighting bulls, whose ferocity was artificially maintained in order to give solace to the unemployed, the breeder thus giving a patriotic character to his activity" (*5,* p. 239).

Since the Middle Ages, this vast, fertile, alluvial plain has been devoted to the pasturing of cattle and horses. There was enough moisture in the subsoil to support a good stand of grass even during the parched summer months, when the stock wandered from water hole to water hole under the guidance of picturesque cowboys. In the course of the 19th century, vast acreages were given over to the pasturing of the fierce bulls used in the national sport.

The homes of those who are engaged in breeding bulls stand out on the plain like feudal castles, as indeed many of them seem to be (Fig. 1). It is stated that bulls pastured on the grass native to this alluvial plain are more fierce than those raised elsewhere, and those whose strain of *bravura,* or ferocity, has decreased are brought here for two or three generations to be improved.

Modern Agriculture in the Seville Sector

What Sermet writes of Mérida and vicinity is just as applicable to the rich alluvial valley of the Guadalquivir (*6*): "It is difficult to run counter to the indifference of men, for what has weighed especially heavily is the great landed property; it

is concerned only with grazing. Hence these extremely fertile soils have lain dormant for centuries. Yet what are they not capable of! The proof is that wherever cultivation has been undertaken it has prospered." Very early during the terrible social and political upheaval of the civil war, a serious food shortage developed, and in the national emergency it was seen that at least some of these enormous fertile tracts should be used for the production of food.

Both the soil and the climate are favorable for the production of rice. Further, extremely fertile, level land was available in large blocks, and the necessary installation of irrigation works could be made on a large scale by those who had ample capital.

In 1937, work was begun in this area by Pedro Beca. Enormous pumping stations, with a capacity of 24,500 liters per second, were installed to lift water from the Guadalquivir River into irrigation canals (Fig. 2). Drainage is as important as irrigation, for the fresh river water flushes out the salts as it soaks into the soil, and makes it possible to produce a crop of rice. Between the crops of rice—a summer crop—one crop of wheat or oats can be grown. Enough rain falls in winter and spring to support these grains. When the attempt is made to grow two nonirrigated crops in succession, enough salt rises by capillary action to destroy the second crop. The water table for the whole area of the alluvial plain is not far below the surface. Beca has a well only 30 feet deep from which he can take a 4-inch stream of water indefinitely. When the pump starts up, the level in the well rapidly goes down 3 feet, but there it stays no matter how long the pump runs. Water from this well is used to irrigate the flower garden around the house.

In a few years a neoplantation has come into being. Some 25,000 acres of semiarid land have been transformed into bright green rice fields. The Beca firm has its own rice-drying, storing, and milling facilities (Fig. 3), and a small rice paper factory, which now produces more than 3 tons of paper a day and which is being enlarged to turn out more than 10 times that amount. There are 40 miles of main irrigation ditches and 360 miles of secondary channels; there are 30 miles of main drainage ditches and 270 miles of secondary ones. One hundred miles of dikes had to be constructed around the fields so they could be kept covered with the right depth of water at the right time. Irrigation channels have to be cleaned of silt every so often. Beca has found that it is cheaper to hire men and donkeys for this task rather than to do it mechanically. At one time he had as many as 2000 donkeys and 3000 workmen engaged in this task.

The value of an acre of unimproved land that cannot be irrigated is about $30. Land with good prospects for improvement by irrigation is now selling from $200 to $250 an acre, while land actually under irrigation is worth from $500 to $750 an acre, depending on its accessibility, the salinity of the soil, and the amount of irrigation water necessary for irrigating and flushing it. Some of the very best improved land is worth as much as $1000 an acre.

To man this mammoth farm there are some 320 small-plot farmers and their families, 80 percent of whom came originally from Valencia and who were familiar with the growing of rice. Of these, 170 are *colonos* (small-plot farmers) who came originally

Fig. 1. View from P. Beca's country home across the floorlike expanse of the flood plain of the Guadalquivir River, long used as grazing areas for fighting bulls, which are to be seen in the upper right-hand corner.

Fig. 2 (left). Main pumping station on the Guadalquivir to supply water for the great rice fields. Fig. 3 (right). The rice huller.

as renters but who now farm from 20 to 75 acres apiece, which they have acquired by installment payments, generally over a period of 5 years (Fig. 4). These men with their families work a total of 17,000 acres, and in a good year they realize up to \$40 or \$50 a year per acre. Although the land is theirs, they are not exactly free agents in the matter of the crop grown, or in the preparation of the soil, or in the planting, weeding, fertilizing, and harvesting of the crop. These items, as well as the marketing of the crop, call for united action among the *colonos* in cooperation with Beca and his associates of the land company. The *colonos* are subjected to a *Flurzwang* (the obligation to follow specific agricultural practices collectively) as rigid as that of the medieval peasant in the three-field system or of the modern *colono* who grows cane for a huge sugar mill.

The other 150 workers and their families cultivate nearly 4000 acres by contract, or *destajo*. These workers are advanced seeds, fertilizer, and fields prepared for planting, and they get a share of the proceeds of the sale of the crop after their advances have been deducted; these workers also realize up to \$40 to \$50 an acre if the harvest is good.

Besides these 320 families of *colonos* and sharecroppers, or contract laborers, three villages have been established that together contain the homes of 1000 more or less permanent workers. Besides, thousands of floating laborers, housed in hugh barracklike structures, are hired as the need for extra hands arises, for planting, weeding, spreading fertilizer, and so on, for the land company, for the *colonos*, or for those who are working plots on contract (Figs. 5 and 6).

One great estate owner (*latifundista*) pointed out that a fine feature of the labor force was that it did not deteriorate, whereas an idle machine not only does not make money but depreciates in value with disuse. Fortunately, it was pointed out, this was not true of human laborers. The seasons of rice planting and harvesting induce great seasonal migrations of laborers. High seasonal unemployment is augmented by dependence on a single crop and the small use of agricultural machinery, except in harvesting. From the hill towns and *municipios* of southern Andalusia, thousands of laborers migrate northward to the rice fields south of Seville. Seasonal unemployment means a lower standard of living generally, because of the loss in potential production, and it is at the root of much social unrest. It is unfortunate that the excess of rural population cannot be absorbed in urban industries, but must rather migrate from areas of much wretchedness to areas of less wretchedness—and this only temporarily. Only where cheap labor exists in such quantity can it be used so prodigally.

A leading expert on Spain observes, "The system in use on these large estates is to keep a handful of men on the payroll all the year round and to take on the rest for short spells as the season requires. For every ten that are permanently employed, a hundred will be at the mercy of casual labor. This means that, even in a good year, an agricultural laborer will have to support his family for twelve months on what he earns in six or eight. Before the Civil War it was just possible for him to get along in this way when the season was not too bad, but now, owing to the inflation, the value of wages has fallen considerably" (*7*).

The harvester (*5*, p. 240) particularly the combine-harvester, was considered by some to be a defensive weapon—the heavy artillery—of the great landowner against the poverty-stricken, landless wage-earner. It made it possible to do in a matter of days the job of threshing that had formerly consumed weeks or months by the old method of trampling out the grain by driving horses round and round over the sheaves. The threshing season was formerly the season when demands for higher wages and better working conditions might be

Fig. 4. Houses of foremen, many of them originally from Valencia, who are given an interest in the business by being allowed to purchase 20 to 75 acres of land.

made with some possible chance of success. The mechanical harvester, practically precluding the possibility of a strike, assured the landlord of his harvest at the same time that it saved him money in wages. This is as true of the big rice grower as it is of the grower of wheat or other grains.

Problems of irrigation are intimately interrelated with those of flood control, soil conservation, reforestation, and the development of hydroelectric power, yet the irrigation feature alone has been developed in the flood plain of the lower Guadalquivir Valley. This one-sided development is having the effect of swamping existing markets with produce that competes directly with that of the old established irrigated zones. The creation of new markets has been neglected, and the standard of living of the poorer classes of the towns has not increased enough to help these people absorb the increased agricultural production. It is of no advantage to have one of the highest yields of rice per hectare in the world if there is no market for it. And this is precisely what is being experienced with large-scale rice production in the Seville area. Indeed, it is immaterial to the large-scale farmer in the Seville area whether he produces rice on a neoplantation or fighting bulls on unimproved pastures. Little thought has been given to producing a crop that would be an integral part of the regional economy, and the rice farmer especially has in effect put down what might be termed adventitious roots. City and country here seem to be less in rapport than in the Valencia sector of eastern Spain.

Development of the Valencia Sector

The city of Valencia is situated in the center of a very densely populated lowland, with more than 1100 inhabitants per square mile in the cultivated area around the city, where two to three crops per year are the rule. The traditional garden land, or *huerta*, as irrigated by the seven canals of the Tribunal de Agua, is 28.5 square miles in extent, 20 percent of which is occupied by the built-up area of the city.

Valencia was a relatively unimportant colony under the Romans, but under the Moors it rapidly evolved into a great agricultural center on its extremely fertile *huerta*, drained and irrigated under the high standard of agriculture for which that people has become famous. As the town and its fertile garden land became closely integrated, the basis was laid for its commercial prosperity. Agricultural production stimulated the industries of flour milling, silk weaving, and hemp manufacture. Paper products and ceramic ware from the hinterland were exported through the port of Valencia.

In the 11th century, with the breakup of the Caliphate of Córdoba, Valencia became a political as well as an agricultural and commercial capital, and retained this position for some two centuries. As the political structure of the Moslems on the peninsula began to disintegrate root and branch, Aragón took over Valencia, and on this extremely fertile land irrigation channels were kept up. The Moors were not expelled en masse; thousands of them were converted and continued their traditional farming practices. They had been growing rice for generations.

The historical background of rice culture in the *huerta* is an important factor in the evolution of small-plot farming. The system of *arrendamiento* in Valencia is a kind of land reclamation. Since the farmer himself reclaimed dry land or marshland, he obtained the right to will his lease, called *censo*, to his heir or to divide it among the members of his family. During the past century, many tenants have bought their holdings, which they now hold in fee simple. By irrigation and interculture, three crops can be grown on them in 1 year. Hence, a very small area is sufficient to support a family. A man is considered rich who owns 4 hectares (1 hectare = 2.47 acres) of this irrigable *vega* land. Agricultural wages are said to be higher here than anywhere else in the peninsula. During the seasons of rice planting and harvesting, laborers from the dry, rainless areas to the west and south swarm into the rice fields of Valencia, adding some 25,000 seasonal laborers to the 25,500 who are permanently employed. Many workers travel in horse- or donkey-drawn carts with their families; most of the men, however, migrate alone, and the women employ their time in lace-making. Seasonal migration has been practiced for so long that it is a recognized feature of the regional economy. The migrant works for the same farmer, or farmers, year after

year. The single man boards with his employer; the man who travels by cart with his family camps on the same spot each season. In other words, the permanent residents and the migratory laborers are in rapport.

A Community Enterprise

The *huerta* was irrigated by seven *acequias* or canals and was controlled by the Tribunal de Agua within the city. An eighth canal was used to flush the sewers of the town and water its gardens. Peasants of the *huerta* and the townspeople, dependent on the eight canals from the Turia River for their agricultural crops and for public health, joined together in defense of their water rights against the encroachments of communes upstream on the Turia. Even today the communes of the *huerta* elect a tribunal of peasant cultivators that meets every week in front of the cathedral in Valencia to discuss their proble s, hear grievances, and fine malefactors.

The Water Court (Cort de la Seo) is in session every Thursday morning at 11:30, as it has been since the early Middle Ages. This tribunal is simply one of the many proofs of the capacity of Spanish rural communities for organization and discipline. The seven judges sit on an old sofa in front of the door of the Apostles of the Cathedral and are the final court of appeals for those with disputes. Declarations of witnesses are heard by the judges, who have no scribes and take no notes. This is preferable for the peasants, who are afraid of lawyers and "paper writing." Sentence is pronounced immediately with the finality of those who know that their decisions will be carried out. Anyone insolent to the court is fined, and, although fines cannot be enforced by law, they are invariably paid; anyone who refuses to comply with the sentence has his water supply cut off, for good and all, which means that he is through as a farmer in the *huerta* of Valencia. But the working people look with great respect upon the judges, workmen like themselves, whose sentences are final. They are in effect the owners of the water, and in their hands are the very lives of all who depend on irrigation water for their fields. Fortunately, water rights here are attached to the land, and a host of abuses are thereby avoided. The people who elect the judges call them by the name of one of the seven irrigation canals they represent. A sitting of this Water Court is graphically described by V. Blasco Ibañez in *La Barraca*.

The rice growers in particular, who are dependent on a certain amount of water on fixed dates, have for centuries been vitally interested in the steady functioning of irrigation canals. There is a marked contrast between the Seville and the Valencia rice growing sectors, both in size of holding and in number of people engaged in rice culture. Of the 32,891 rice cultivators in the Valencia district, who work a toal of 25,795 hectares, 15,291 landowners cultivated 12,524 hectares, 17,292 renters cultivated 13,080 hectares and 308 sharecroppers cultivated 191 hectares. This does not include rice land used for a catch crop. More than 16,000 farmers work less than one-third of a hectare (Fig. 7), and another 10,000 cultivate more than one-third but less than a whole hectare. Some 5000 work plots are from 1 to 3 hectares in size, 1200 are from 3 to 10 hectares, and only 110 have total acreages in excess of 10 hectares (*8*).

Rice Growing and Land Reclamation

Not all of this land was *secano*, dry land awaiting only the application of water to make it blossom as the rose. Much of it was marshland reclaimed at the expense of the body of water still known as the Albufera, the lagoon, the Arabic name given to it by the Moors (Fig. 8). Into the marshy flats around this lagoon, cut off from the sea by a wide, dune-

Fig. 5 (left). Every stock of rice grown on the 25,000 acres is planted by hand. Fig. 6 (right). Weeding is also done by hand. Note the barracklike structure in the distance, in which floating labor is housed.

Fig. 7. Typical small plot of rice at Catarroja, with plots of cabbage, onions, and beans in the background.

covered sand bar, rice culture was introduced by those excellent hydraulic engineers, the Moors, who were no less ingenious in reclaiming land having too much water than in devising specialized dry-farming techniques. This process of land reclamation has continued steadily since the reconquest. During the past two centuries, more than 11,000 hectares have been reclaimed for rice fields. This gradual encroachment upon the lake by the rice cultivators brought them into conflict with the fishermen of the lagoon, who considered themselves the hereditary owners of the Albufera. The ancient village of El Palmar (Figs. 9 and 10) was originally founded on a tiny island in the lagoon, but now that the water level of the Albufera has receded, the island is connected by road to Valencia; its fishing rights date back to the 13th century, but its inhabitants have been unable to prevent the gradual shrinking in the size of the Albufera and the marked diminution in the supply and catch of fish. The cultivators control the water level by means of sluice gates and, especially in the summer months, a large part of the fish in the rice fields is

Fig. 8. Diesel-powered water wheel lifting water from the Albufera for use in irrigating the rice fields.

lost to the fishermen. At the same time, there has been a marked increase of population. The upshot of the struggles between cultivators and fishermen has been that many of the latter have been forced to adopt the despised occupation of rice cultivation, on a part-time or even on a full-time basis (*9*).

Rice Culture and Malaria

Since the periodic outbreak of malaria associated with rice cultivation was a recurrent problem, in 1562 rice growing was prohibited within a radius of 1 league of the town (Fig. 11). This law has been enforced at intervals during the following centuries. The rapid strides made in antimalarial measures have considerably diminished the havoc wrought by the disease, but it is by no means eliminated. Refugees from Andalusia during the Civil War introduced the malarial parasite into the Valencia area and created a new epidemic that was particularly severe in the lower-lying sectors around the Albufera. During the years 1942–46, Valencia had 23,296 cases diagnosed as malaria, an annual average of 4.6 per thousand of the population (*10*). As long as this reservoir of infected *Anopheles* mosquitoes exists, the people who work in the rice fields will be infected by this disease that in epidemic form has wiped out thousands of people over the centuries. Fortunately, there is a collective feeling of responsibility for this dread scourge, and vigorous steps are being taken by municipal authorities to eradicate it.

The Federation of Rice Growers, under the leadership of able, dedicated men, does all in its power to promote the interests of producers. An outstanding experiment station, where experiments on every phase of rice growing are carried out, is maintained at Sueca, a rural village in the heart of the rice sector south of Valencia. Technical advice is available to the grower at all times. There is a vigorous sales campaign, and pamphlets on how to prepare savory dishes of rice are distributed. Hence, although the per capita annual consumption of rice for Spain as a whole is but 6 or 7 pounds, it is many times that amount in the *huerta* of Valencia.

Conclusions

Although the division and subdivision of holdings is greatest in northwestern Spain, where the great density of agricultural population is related to *minifundia*, it is in the arid lands of the south where the highest rural unemployment is to be found, and there it is related to the great landed estates, or *latifundia*. The present government of

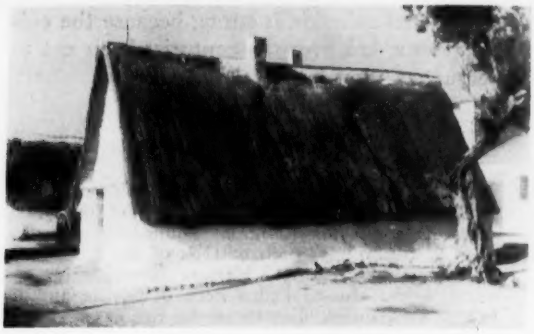

Fig. 9 (left). A barraca or worker's permanent home in El Palmar, formerly a fishing village on an island in the Albufera. The tiny wooden cross on the gable is a survival of the period of the Reconquest when those living in houses without crosses were driven out by the conquering Aragonese. Fig. 10 (right). Behind the houses of El Palmar runs the canal in which clothes are washed and on which rowboats ply to all parts of the low-lying rice fields.

Spain, hoping to diversify Spanish agriculture and thus cut down on the excess of rural population and the great numbers of seasonally unemployed, has embarked on an ambitious program of irrigation projects. The project to colonize new zones has a high propaganda value for the present government, with the result that the bigger problem of *latifundia* is sometimes neglected. The breakup or more intensive use of the *latifundia* and the more intensive use of the dry-farming, or *secano*, lands are other partial solutions to Spanish agrarian problems which have perhaps not received the attention due them.

It has been seen that in the flood plain of the lower Guadalquivir vast tracts of land have been reclaimed by the installation of large-scale irrigation works. Some 25,000 acres of once semiarid land have been made productive in a few years, a cultural landscape that has sprung full-grown from the brow of modern technology and machinery, as did Minerva from the brow of Jove, a neoplantation of heroic size. The whole industry is directed largely by one person, and the area under cultivation is still being expanded. The rice is grown with an eye to the international market. Indeed, 30,000 tons were shipped to Japan in 1955. Wherever rice will thrive, anywhere in the world, it is perhaps possible to cover a food deficit more quickly by growing that cereal than by growing any other.

Rice culture in the Seville sector is based on a lavish use of low-cost, seasonal laborers from the hill villages, who have no rapport with management and no stake in the land or industry itself. Only the harvesting of the crop is mechanized. Regions of *latifundia* everywhere and always seem to suffer from chronic unemployment or underemployment, whether as manorial holdings during the Middle Ages, worked by serfs, or, as neoplantations today, manned largely by hordes of poorly paid migratory laborers. The few towns of the plain swarm with dejected beggars and dirty children, but their economic situation, low as it is, is perhaps somewhat better than that of the hill villages (Pueblos of the Sierra), whence come the droves of poor laborers for the seasonal jobs on the plains. Andalusia is thus seen to be a region of cleavages—between the villages and the plain, between the haves and the have-nots, in sum, between the few landed and the many landless, most of whom are utterly without hope. As Pliny long ago wrote, *Coli rura ab ergastulis pessimum est et quicquid agitur a desperantibus* (*11*). (It is bad practice to till the fields with workers from slave barracks, or to have anything done by men without hope.) Indeed, this cultural landscape is being cut to the measure of mass man and of the machine; hence it is not a cohesive force in regional development.

In the *huerta* of Valencia, it has been seen that rice culture, started by the industrious Moors, has been an instrument in the reclamation of dry land and of marsh land. The present cultural landscape

Fig. 11. Strip of rice growing in the bed of an arroyo in the very outskirts of Valencia—in defiance of the city ordinance, be it noted.

has evolved slowly and painfully, step by step, over the centuries, down to the present. Rice is grown in a few sectors in large plots on a one-crop basis, but in general it is grown on small plots in a system of interculture, which gives a greater spread of labor than is enjoyed in an area of one-crop farming. Further, the highest yield of rice in the world is reported in the huerta (2500 pounds to the acre) (*12*). The crop itself is largely for domestic consumption, usually in the form of the internationally famous dish known as *paella Valenciana,* a dish of rice with sea food, meat, or chicken. Rice growing is an integral part of the whole regional economy, a significant factor in the evolution of a closely knit regional unit, socially, linguistically, and economically.

The city of Valencia and the irrigated plain or *huerta* are so well integrated economically that the urban center and the farmlands have for centuries been considered as one unit. The land is cultivated to the very edge of the built-up area, and land values are so high that there is no suburban growth except for ribbon settlements along the main roads. Indeed, the actual suburbs take the form of small towns and agricultural villages in a belt on the edge of the irrigated plain, between the hill lands of the *secano* and the irrigated *huerta.* The municipal boundaries of Valencia still include 28 square miles. Centrifugal political tendencies there may be, but regional cohesion is strong because the cultural landscape has over the centuries been cut to the measure of man.

References and Notes

1. The field and library work on which this article is based was made possible by a grant of the John Simon Guggenheim Memorial Foundation. Thanks are due to administration officials of the University of Florida for creating a climate favorable for research work; also to Pedro Beca of Seville and to Jose de Oyanguren, director of the rice experimental station at Sueca (Valencia), for their many courtesies.
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Nature of Genius

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ONE hundred years ago there came into life a being whose long years of work and insight were to make such contributions to knowledge as profoundly to influence the civilization of every country. And we may safely say that the full impact of that influence has yet to be experienced. Whoever stands in my place in another 100 years from now will in his commemorative speech—and I am confident there will be one—be able to report further progress in the assimilation and application of Freud's discoveries to an extent which it is impossible for us now to predict.

I chose the title of my lecture for its brevity, but it would have been more modest and more accurate had I entitled it "Some of the factors conditioning the workings of certain forms of productive thinking." You will allow me to rectify it in this sense.

There is a quite stupendous literature on the subject of what Ostwald called "geniology," which would necessitate a large volume merely to summarize. This is certainly not the place to attempt any such compilation, but it is worth while commenting on the relative fruitlessness of so many of the attempts to solve the problem of genius. I should attribute that largely to the emotional ambivalent attitude so commonly shown in the approach to the topic. It has been well said that "there is a sort of doom overshadowing the very conception of genius: everyone who approaches it is drawn into a murky orbit of adoration and contempt, idolatry and scorn, profundity and shallowness." On the one hand, there are the writers who display a dithyrambic narcissistic identification with geniuses which allows the authors to praise their own glory under the guise of adoration. The Marquis de L'Hôpital asked: "Does he eat, drink and sleep like other men? . . . I represent him to myself as a celestial genius, entirely disengaged from matter." Such writers indignantly deny that genius has any relation to mere talent. De Quincey, for instance, maintained that the two are "not merely different, but are in polar opposition to each other." One author even regarded genius as "a psycho-biological mutation," from which it is only a step to contemplating the future selective breeding of geniuses.

On the other hand, more envious writers have labored to find various ways of directly or indirectly disparaging men of genius and their achievements. The most popular one, from the time of Lombroso and Nordau onward, is to insist that geniuses are psychopaths and mostly tainted with insanity, their achievements being lucky and more or less accidental by-products. The literature on this aspect of the problem is very extensive, but I have not found it illuminating. One can also detract from any credit due to the genius by asserting it was the result purely of heredity, so that we owe him no praise. One of the most original writers on the topic, Lange-Eichbaum, goes so far as to maintain that what constitutes a genius is the height of the fame to which his worshippers raise him, this being the reason why the decision of who precisely is a genius varies from period to another. But perhaps he did not sufficiently distinguish here the matter of subjective recognition from that of the actual objective achievement.

In the first place we may ask whether there really is such a thing as genius—that is to say, any attribute that differs essentially in its very nature from those present in all human beings. It is a question that has been often debated, but I propose to answer it from the start with a decided negative, and in doing so I find myself in agreement with such a high authority as Kant. All Freud has taught us concerning the regular laws of mental development goes to confirm the view that the manifold differences between various individuals, and indeed between the various races of mankind, are quantitative rather than qualitative, and this conclusion is only slightly modified by the reflection that a quantitative difference may on occasion be so striking as to give the impression of something qualitative and absolute. The question seems to me to resemble that concerning the presence in mankind of something qualitatively different from anything present in other animals—namely, the divine gift of a soul—and I need hardly say that this also

finds no support in either biological or psychological researches. Indeed, the original meaning of the word *genius* was a designation for a semidivine spirit who on appropriate occasions visited certain fortunate mortals and inspired their creations, after which it could presumably wander forth in search of other habitats. We still retain this sense of a discarnate spirit when we speak of a *genius loci* or of the *genius of a language* which institutes changes independently of any individual volition. It was only in 1700 that the term began to designate the actual person who was thought to be inspired by something mysterious within.

We apply the term *genius* more often to artists, particularly poets, whose intuition at times seems to border on the miraculous, than to men famous for more purely intellectual achievements. It is very possible that the conditions of creative genius are not identical in these two groups. At all events I am so much less at home with the former that I propose here to refrain from any consideration of its nature and will refer you to Ernst Kris' masterly study of artistic creativeness. Even the intellectual group itself is by no means homogeneous. We speak of the genius of Napoleon, for instance, because of the degree in which both his military and his administrative capacities transcended those of the average being. I will therefore narrow my field still further to that of scientific production of the highest order.

Attributes of Genius

The number of those whose claims to belong to this Olympus are universally recognized is very small. After listing such names as Newton, Darwin, and Einstein we begin to enter a more debatable territory. "The genius of Freud" is a phrase that has been used so widely that I think we must subscribe to a truth contained in it. Characteristically enough, Freud himself vehemently dissented from its being applied to him. Even as far back as 1886, when he was 29, he wrote to his betrothed: "There was a time when I grieved that Nature had not, in one of her gracious moods, impressed on me that stamp of genius as she sometimes does. Since then I have long known that I am no genius, and I no longer understand how I could have wished to be one. I am not even very talented; my whole capacity for work probably lies in my character attributes." On one occasion in later life when it was applied to him he burst out with the protest: "Geniuses are unbearable people. You have only to ask my family to know how easy a person I am to live with. So I cannot be a genius." This disclaimer, however, was based on a very partial definition of genius, so we need not take it too seriously. But to ask in what sense the term can properly be used of Freud leads us into the heart of our subject and raises a number of difficult problems.

The numerous attempts to define genius have not proved very helpful. On one occasion some 30 definitions were listed, but for present purposes we may be content with the definition offered by the *Encyclopaedia Britannica* as "the highest conceivable form of original ability, something altogether extraordinary and beyond even supreme educational prowess." One notes here what is certainly a characteristic attitude of the beholder, that of astonishment or even amazement, one that is doubtless the source of the intense admiration the productions of genius so often evoke. It gives rise to the notion of mystery about the achievements of genius, and hence to that of its supernatural nature. Of all their characteristics Révész selects this one of *surprise* as being the most central, to which all others are accessory, and he perspicaciously remarks that it is typical for this feeling to be repeated, however often one contemplates the achievement.

Intuition; Spontaneity; Periodicity

This seems to accord with the frequency with which geniuses often receive their inspiration in a sudden flash that startles the recipient himself. It is a feature that has always been recognized. Both Plato and Aristotle commented on it, and they associated it with the divine source of the inspiration. The description of Apollo in the third book of *Hyperion* seemed to Keats to have come by chance or magic—to be, as it were, something given to him. He said also that he had often not been aware of the beauty of some thought or expression until after he had composed and written it down. It had then struck him with astonishment and seemed rather the production of another person than his own. Alfred Russell Wallace wrote: "Finally both Darwin and myself, at the critical period, had our attention directed to the system of *positive checks* as expounded by Malthus in his *Principles of Population*. The effect was analogous to that of friction upon the specially prepared match, producing that flash of insight which led us immediately to the simple but universal law of the 'survival of the fittest.' " This is, however, a feature by no means always present. The flash of insight which Wallace described did presumably happen to him, but Darwin himself seems to have reflected on the suggestion more calmly. No one can have accepted revelation more tardily and gradually, even cautiously and very timidly, than Darwin, whose dawning vision came only as the result of many years of hard work.

In a disquisition on this element Lessing wrote:

"How many conclusions would seem theoretically irrefragable had not genius succeeded in demonstrating the contrary," a statement that applies peculiarly aptly to much of Freud's work. In describing a recent discovery in physics Gabor made the interesting remark: "This statement has that touch of offending common sense which is the hallmark of every truly important scientific discovery." Freud's discoveries satisfied this criterion in full measure. Many philosophers and psychologists have shown conclusively that in theory there can be no such thing as unconscious mental processes, and our common sense fully agrees; yet, as Charcot said in a phrase Freud was fond of quoting, "ça n'empêche pas d'exister." I think we shall agree that there was enough of this element of surprise with which Freud's work has been greeted to warrant our attaching at least this one to the attributes needed to qualify for the title of genius.

Allied to this feature of intuitive inspiration is the characteristic spontaneity with which the productions of genius appear. They can never be brought about by a deliberate effort of will, and nothing can ever force them. Lowell has wittily said that "talent is that which is in man's power; genius is that in whose power man is," and Voltaire with equal wit expressed it thus: "The works of genius are to compilations what love is to marriage; Hymen comes when one calls and Cupid when it pleases him." Most writers on the subject are agreed that the achievements of a genius are out of his power. Goethe, who could speak from personal experience, laid it down that "all productivity of the highest kind, every significant piece of insight, every discovery, every great thought that proves fruitful and leads to further consequences, stand in the power of no one, and are beyond all earthly might. A human being has to regard them as unhoped-for gifts from above which he has to receive and revere with joyful thanks." Another poet put it in this way: "Genius does what it must and Talent does what it can." It is clear that this attitude of passive surrender toward the flowing in of the valuable ideas must be significant for the psychology of the productive process.

A third feature which has often been noted is that of periodicity. Moebius, for example, made a study of the cycles of productivity displayed by Goethe, and the same feature has been noted with Beethoven and many other geniuses. Freud himself often maintained that his productivity was at its maximum in cycles of 7 years, though he had to strain the evidence somewhat to make it fit this precise span. Still, his most original productions are only a year or two out from his estimate. "Cocaine"; *Aphasia; The Interpretation of Dreams; Theory of Sexuality; Totem and Taboo; Beyond the Pleasure Principle; Inhibitions, Symptoms and Anxiety;* and the *New Introductory Lectures* make a series that approximate to this observation. As might be expected, the notion of periodicity has been interpreted in clinical terms of cyclothymia, but with only occasional evidence in support of this. Freud, for instance, despite plenty of external grounds for despondency, suffered from only one mild and transitory attack of depression in his whole life, and his variation in moods never transcended the normal ambit. It seems to me that most of these cycles in productivity are sufficiently explained by the natural rhythm of life, particularly the variations in libidinal tension that belong to this.

The features just described may be encountered indiscriminately with all forms of genius, and I shall now consider three or four further ones which are much more characteristic of scientific production than of artistic inspiration. The most obvious of these is the indispensable one of absolute honesty. It was Goethe who laid down the law that "the first and last task required of genius is love of truth."

Originality

Then we come to the somewhat vexed matter of originality. It is certainly a more frequent occurrence for a man of science to make a new discovery than for a poet to invent an entirely fresh theme or even phrase, but, on the other hand, the title of genius is only very occasionally bestowed on the discoverer of new facts or ideas in science. W. H. George, in his interesting book *The Scientist in Action*, has drawn what impresses me as a very valid distinction here between what he calls the *new* and the *essentially new*. The simple *new* concerns discoveries of a new fact which may never have been known before. Or it may concern a theory which modifies a previous one by adding some new consideration or factor. The *essentially new*, however, signifies an entirely fresh and different way of looking at things. Wordsworth shortly defined an act of genius as "the introduction of a new element into the intellectual universe." Thus Einstein's theory of relativity, although it modifies and adds to Newton's theory, was not evolved out of it as an extension; it came about from looking at certain physical phenomena in a radically new way.

George gives two examples to illustrate his point, and they are worth quoting. As a result of Sir Joseph Thomson's classical experiments, the phenomena of atomic physics were for 30 years described in terms of a particle of electricity, the now familiar electron. This concept served admirably to account for a wide range of phenomena, but certain optical ones caused a difficulty. Then de

Broglie, in 1925, introduced an entirely different way of regarding an electron—namely, in terms of a wave—and to this day both of these concepts have to be used for different purposes without any conclusion having been reached about which of the two is the more fundamental. Then, again, for eons—in fact, until the turn of this century—all disease had always been regarded as being due to something which was not present in health attacking the body, whether this was a malignant demon, a draught of cold air, or an infectious agent. Drugs and other forms of treatment were simply designed to counteract the harmful things that were producing the illness. It was not until within living memory, in observations on scurvy culminating in Gowland Hopkins' brilliant experimental work, that it occurred to anyone that various diseases could be due merely to the absence of something in the body. That was an essentially new way of looking at the matter, and it has resulted in our present mass of complex knowledge about the various vitamins.

Darwin's doctrine of natural selection is another good example of an entirely new way of regarding the complex phenomena of living creatures. This feature has been commented on in respect of Freud. I will quote from a recent writer: "From time to time men of outstanding gifts alter our outlook on the world in one relatively restricted field or another. But changes in the fundamental categories in terms of which we interpret the world and each other, in the very framework of our thought and language, are rare in history; and more rarely still can we attribute such a change to one man. But about Sigmund Freud there can be no doubt."

A New Idea

Freud's genius is peculiarly interesting in that it has led to looking at mankind in an essentially new way, although what he actually discovered was not in itself so very new. It has been possible to trace most of Freud's ideas to earlier sources; whether he actually obtained them in that way or only from his personal investigations is another matter. That holds good for this division of the mind, with a moral conflict between its two halves; the importance of sexuality in human life and even its specific connection with the psychoneuroses; the significance of repression; and so on. In fact, so far as I know, there was only one idea he discovered which had never been previously recorded. It was a very important one: the universal fear of castration among men. Henri Ellenberger, who has devoted some years of research in the matter, extending through medieval to classical times, assures me that in spite of the age-old custom of castration in various communities he has not been able to find any mention of the *fear* of it in the writings of any historian, philosopher, or even psychiatrist. I have, however, recently come across the record of a patient who suffered from complete impotence as the result of his dreading castration at the hands of his father as a small child, and who was restored to complete potency when that fear was removed. The episode took place some 3000 years ago, and the gentleman was given the name of Iphiclus, "famous might," so the cure was very thorough. Psychotherapists received high fees in those days. The particular one who effected this cure, Melampus, who was reputed to antedate Aesculapius as the first physician, received a third of a kingdom and the king's daughter for his wife as a reward for curing her of a frenzy. In those days marriage with an ex-patient was not frowned on.

That for 3000 years this dread fear was never mentioned is a testimony to the desperate efforts we make to prevent ourselves from becoming aware of it. Freud may, of course, have been cognizant of the story in Greek literature, but if so it would afford one more illustration of the peculiar nature of his genius. For this consisted not so much in the discovery of new things but in the fearless and pioneering exploration of them. Through his detailed investigations, and not at all by personal propaganda, he compelled a section of the community, those with ears to hear, to accept a number of unwelcome but extremely important truths. He took seriously what had previously been hinted at, often merely whispered, and there is no doubt that an unusually high courage was an essential element in the achievement of his genius. Furthermore, although some achievements of genius have an unmistakable relation to the atmosphere of the period when they were accomplished, so that one feels someone else would surely have done the same thing, this was assuredly not true of Freud. One may legitimately doubt that anyone else would have come forward had Freud not done so. We might well have had to wait another 100 years or more for someone of his stature.

Sense of the Significant

Closely akin to this mysterious feeling for what is true seems to go a sense of the really significant. This enables a genius, or compels him, to generalize a finding where a lesser mortal would have cautiously gone on collecting more evidence before venturing on a general statement. Freud, although he would be accounted a man of sober and reflective judgment, afforded several instances of this

kind of superlative boldness and sureness. When he discovered in himself the fear of castration he felt instinctively that the same must be true of all men, and when he also came across the Oedipus complex he did not hesitate to hold it valid not only for all those now on this earth but also for those who populated it many thousands of years ago. These were breath-taking generalizations, and it is not surprising that so many have balked at accepting them or have tried to limit them to certain societies only.

This remarkable capacity for perceiving with somnambulic sureness what is absolutely and universally true is of great interest. It transcends the simple love of truth itself, essential though this may be. I think it must occur at special moments when there is an unusual, and often only temporary, fusion of all the elements in the mind in a peculiar degree of harmony. The sureness arises from the completeness with which the ego is receiving in an unquestioning fashion the message from the preconscious. At that moment there is a complete coincidence between the striving of the id, the permission of the superego, the acceptance by the ego, and the external perception of the problem being studied. Emerson well said that "to believe your own thought, to believe that what is true for you in your private heart is true for all men—that is genius." Schopenhauer made a similar point when he said: "Always to see the general in the particular is the very foundation of genius."

Power of Concentration

The third attribute worthy of mention here is that of the power of concentration. There is no doubt that in the majority of instances important scientific discoveries have meant a great deal of hard work as well as intense concentration. Buffon, the great naturalist, considered that genius was nothing else than a greater aptitude for patience than that possessed by other men, which is rather like Carlyle's well-known dictum that "genius is first of all a transcendent capacity of taking trouble." Ramón y Cajal, the distinguished neurologist, described the process of scientific discovery as follows: "The ideal case would be that of a scientist who during his period of mental incubation would pay no heed to any thought that is extraneous to his problem, like a somnambulist who listens only to the words of the hypnotizer." And another writer, referring to "the self-surrender so familiar to creative minds," says: "The concentration of such a state may be so extreme that the worker may seem to himself or to others to be in a trance." In that connection there comes to my mind an account Freud's daughter gave me of the time when he was composing the great final chapter of *The Interpretation of Dreams* in the summer of 1899. She recollected that when he was interrupted by being called to a meal he walked as if in a trance, oblivious of his surroundings.

At this point we enter the realm of depth psychology, and numerous problems throng upon us. What is the significance of this extraordinary concentration and intensity? What powerful impulses are driving their way at such moments? For there is every reason to suppose that men of genius are characterized by possessing exceptionally strong emotions and usually a correspondingly strong capacity for containing them. The tension induced by the preceding efforts to find a solution gradually mounts until it reaches a climax. The great mathematician of genius, Henri Poincaré, in describing how he made his own discoveries, said: "One is struck by these appearances of sudden illumination, obvious indications of a long course of previous unconscious work. . . . These sudden inspirations are never produced except after some days of voluntary efforts which appeared absolutely fruitless." Einstein has given a very similar description, and in the Fliess correspondence there are numerous allusions to the exhausting stress and strain Freud experienced in the continuously hard work of attaining his various pieces of insight. Kretschmer speaks of the great scientists' "passionate emotions developing which drive their thought constantly in the same direction, producing the utmost tension until at last a short-circuit occurs: somewhere a spark leaps to a new spot where up till then no human thought had ever passed."

What is the relation of the conscious interest in a particular problem to the unconscious forces that produced so much tension? Müller-Freienfels maintains that what is characteristic is the being thrilled and gripped by the problem in some mysterious way that transcends in strength the mere desire to know, but perhaps he underestimates here the strength of just that desire in the unconscious. It is, however, noteworthy that he compares the thrill in question with the emotion of passionate love, and we are familiar enough with the connection between the sexual instinct and the desire to know; it is a matter that Freud expounded fully in his work on Leonardo. Evidently there must be a special coincidence between the unconscious impulses and some essential feature of the objective problem. In the preliminary cogitation various shiftings and similar mechanisms are going on in the unconscious, the purpose of which is to achieve a sufficient degree of harmony with the censoring functions of the superego by means of which the accompanying

guilt is kept in abeyance. At the successful moment there must have been achieved a quite remarkable degree of integration between the ego, the supergo, and the id. It is no doubt this successful degree of synthesis, the overcoming of all barriers, that accounts for the sense of elation at the final moment of triumph. As is well known, such a complete synthesis is rarely more than a temporary one. The superego which has been circumvented soon resumes its sway, and elation is followed by self-criticism, disparagement, and even doubt about the solution reached. I have described at some length these phases which Freud underwent during and after one of his most difficult achievements: the composing of *Totem and Taboo.*

Prerequisites of Genius

I now come to a modest contribution which I think could be made to our knowledge of the conditions governing the productivity of genius. It had long struck me that an essential prerequisite of such productivity must lie in a particular skepticism on the part of the genius. He must have refused to acquiesce in certain previously accepted conclusions. This argues a kind of imperviousness to the opinions of others, notably of authorities. Furthermore, he often has the capacity of seeing the existence of a problem where others have passed it by; he has refused to take something for granted as being either without meaning or too insignificant to bother about. This aloofness sets him free to speculate and investigate. The classical example of skepticism being deliberately employed is of course that of Descartes, who tried to start by doubting everything. The task, however, proved harder than he had expected, and his skepticism did not prevent him from indulging in rather wild speculations in his theory of vortices.

I once asked Freud what he thought was the explanation of the extremely free thinking that scientific pioneers and discoverers must have. He did not answer the question directly, but he pointed out that such freedom is always obtained under the condition that another aspect of mental functioning is inhibited. The example he took was that of Forel. In the face of the puritanical atmosphere with which he was surrounded in Switzerland, Forel ventured to publish a book on sexual problems which at that time was considered shockingly outspoken. On the other hand, he became an extremely bigoted opponent of the custom of imbibing alcohol in any form. His fanaticism in this respect was so intense as to leave its mark on the present-day Zurich with its flourishing *Alkoholfreier Verein* that is to be seen nowhere else. He infected his successor Bleuler with the same fanaticism, and Jung attributed Bleuler's breach with him to the circumstance of Freud having induced Jung to depart from the faith and to taste the forbidden liquor.

It may well be that the compensatory inhibition of which Freud spoke is the explanation of a feature often remarked in men of genius—namely, a certain naivete, marked simplicity, and ignorance of the ways of the world. One writer even commented on what he called the *scheinbare Dummheit* (apparent stupidity) often found in such men, though this must surely apply only to a small majority. I note, however, that Thomas Mann, in his famous description of Goethe, comments on "the union in one human being of the greatest intellectual gifts with the most amazing naivete."

The skepticism and imperviousness to opinion of which I have spoken were prominent features of Freud's personality, and they extended over a wide field. Not long after getting to know him, however, I was struck by an exactly opposite feature, one which, it is true, operated in a far more limited field. I refer here to a curious credulity, a willingness to believe what he was told, whether it was really likely or not. To it I would ascribe his well-recognized difficulty in forming an accurate estimate of personal character, a deficiency of which he himself complained. In my biography I have given many examples of this credulity, which at times bordered on superstitiousness, but it is worth while commenting on what is perhaps the best-known example of it, since it was that feature which ultimately led him to make one of his very greatest discoveries. I refer to the years when he accepted as true the seduction stories of his patients, which I am sure the vast majority of physicians would have doubted at once and regarded as one more example of the unreliability of hysterics and their tendency to fabulation.

In relating this experience in later years Freud spoke of how despondent and baffled he felt when he found how deceived he had been and that most of the stories were quite untrue. Baffled he doubtless was, but contemporary evidence in his letters to Fliess reveals that, so far from being despondent, he felt a quite inexplicable elation. He wrote the memorable words: "Can these doubts be only an episode on the way to further knowledge? . . . Between ourselves I have the feeling more of a triumph than of defeat." He could not know at that moment, though his unconscious evidently did, that he was on the brink of one of his most momentous discoveries—the significance of incestuous wishes in infancy.

Pascal pointed out that greatness is never at one

extreme but consists of the union between two extremes, an idea which Sainte-Beuve later labeled the theory of the *entredeux*. My own suggestion is a particular application of this.

In a proper scientific spirit I then wondered whether this observation I had made concerning Freud's personality could have any more general validity as a condition for the productivity of scientific men of genius, and the studies I have made of many of them encourage me to think that it may be so. Allow me to relate a few examples. I will start with the earliest in point of time, Copernicus. His work revolutionized our conception of man's place in the universe and reduced his glorious habitation to an insignificant speck of matter in space, so that Sir Arthur Balfour in one of his cynical moments could describe the story of mankind as "a disreputable episode in the history of one of the minor planets." Actually it is not certain that Copernicus was really convinced that the earth revolved round the sun, but he evidently ventured to doubt that the sun went round *it*. So much for his skepticism. His reputation and the immortalizing of his name rest on that alone. But there is another side to the story, which throws light on the motives impelling him to his new conception.

It will be remembered that, starting from the Greek doctrines of perfect heavenly orbits, Ptolemy had constructed an extremely ingenious geometrical scheme of the universe as then known. He found it necessary, however, to introduce a number of what are called epicycles, and moreover to give some of them the form of an ellipse. The scheme worked fairly well for many centuries, but the progress in astronomical knowledge gave it what might be called increasing fits of indigestion which could be cured only by introducing more and more epicycles, so that ultimately the picture became one of bewildering complexity. Many attempts were made in the 16th century to simplify matters, including that by Copernicus. Now what really stirred Copernicus was a feeling of dismay and reprobation at Ptolemy's impiety in daring to depart from Aristotle's dictum that all the heavenly orbs and orbits must have the form of a perfect circle to conform with the perfection of the Divine Creator. Copernicus had an absolute belief in Aristotle's infallibility. Therein lays his credulity. And it drove him to search for methods of remedying Ptolemy's irreverence. He then found that by imagining the sun as the center of the solar system he could devise a scheme, however faulty it afterward proved to be, that could be built up with the desirable perfect circles. So he died a happy man. He was not the first to do the right thing for a wrong reason—Columbus had given an even more spectacular example not long before. Nor was he by any means the last.

Credulity of Great Men

We then come to the greatest genius of all times, Sir Isaac Newton. It would need an extremely expert mathematician indeed to elucidate the elements of skepticism and credulity entering into his great discoveries in science, nor is it likely that the data for doing so exist. On the other hand, it is easy to show that both of these attributes were prominent in Newton's personality. His published scientific work is marked by a rigid objectivity, and it was he who proudly proclaimed the famous sentence, "Hypotheses non fingo" (I never manufacture hypotheses). He resolutely refused even to speculate on the actual nature of light or of gravitation, but contented himself studying their mode of operation. Yet he had in earlier days spent much fruitless time in conducting experiments in alchemy, in the search for the philosopher's elixir, and the means of transmuting metals into gold, and this at a time when alchemy had long passed its prime. Most of Newton's biographers have suppressed the important fact that throughout his life theology was much more important to him than science, and, moreover, theology of a peculiarly arid and bigoted order. There was an astonishing contrast between the extreme credulity he displayed concerning the literal statements of the Old Testament and the skepticism he evinced concerning the cardinal doctrines of the New. He followed Bishop Ussher in dating the Creation from 4004 B.C., and on that basis and the data about the long lives of the patriarchs spent years in conjuring up a chronological history of all the nations of the world, in the course of which he came to unbelievably fantastic conclusions. He was especially engrossed in unraveling the obscure symbolism of the Books of Daniel and of Revelations. From the former he deduced that the tenth horn of the fourth beast must refer to the Roman Catholic Church and confidently predicted its downfall in the year 2000. Similarly, Halley's comet would probably after five or six revolutions fall into the sun so that the earth would be burned up. He was also a devotee of Jacob Boehme's mysticism. Yet, on the other hand, although he was a constant adherent of the Church of England, he subscribed to the Arian doctrines which deny that of the Trinity and even went further in doubting the divinity of Jesus.

Newton had a markedly irritable and suspicious temperament, and much of the controversy that disfigured his life arose from his credulous belief in the statements of overcandid friends. In later

life these qualities deteriorated for a while into paranoic delusions of persecution; perhaps in this connection it is not irrelevant to remark that Newton never fell in love and never married.

Faraday, the supreme physicist of the 19th century, had also his vein of credulousness. He said: "In early life I was a very imaginative lively person who could believe in the *Arabian Nights* as easily as in the *Encyclopaedia,* but facts were important to me and saved me." Throughout his life he was an adherent of the obscure sect of Sandemanians, followers of the religious prophet Robert Sandeman, and for 3 years regularly preached sermons before them. One must place this in contrast with Faraday's exceptional intelligence in other spheres, since it would be commonplace otherwise.

Darwin was a man of far more placid temperament, and it is probable that any turmoil of emotions found their expression in the psychosomatic afflictions to which he was a martyr. Although destined for the Church, he came gradually to doubt the truth of the official religious doctrine that mankind had been created in God's image for the edification and glory of the Lord of the Universe; in this he was influenced by Lyell's work in geology and perhaps also by his grandfather's teaching on evolution. But his skepticism was tempered by a credulous attitude toward other authorities. Even after his great discovery of the operation of evolution through natural selection he still believed in Lamarck's doctrine of evolution through the inheritance of acquired characters, a doctrine his own work had rendered superfluous and indeed erroneous. It was because of it that he developed his extraordinary theory of pangenesis, according to which minute gemmules in the blood convey the acquired alterations to the germ cells, cells which we know now to be impervious to any such influence.

His friend and contemporary Huxley offers a very interesting contrast to the genius Darwin. Although possessing a wider knowledge than Darwin, and gifted with more originality and a greater intellectual daring, Huxley's actual achievements are of a different order. On first reading Darwin's theory he exclaimed: "How extremely stupid of me not to have thought of that." Now, Huxley was endowed with any amount of skepticism, of indeed a rather pugnacious brand. It has been said of him: "He allowed himself no prejudice, no sentimentalities, no illusions." But there is no record in his life of any evidence of credulousness to match it and, according to my view, to enable him to make really great discoveries.

Perhaps it is worth mentioning in the present connection the remarkable epidemic of belief in the cruder aspects of spiritualism that infected several of the leading English physicists early this century: Sir William Barrett, Sir William Crookes, Sir Oliver Lodge, and Sir George Stokes. The number of times the mediums in which they trusted were exposed as frauds made no difference to the tenacity of their beliefs.

Psychoanalytical Considerations

It would not be out of place if I concluded with a reference to some psychoanalytical considerations. The only point I wish to bring forward here is the suggestion of a possible correlation between the credulousness on which I have been laying stress and the characteristically receptive nature of genius. A credulous attitude betokens an uncritical, excessive open-mindedness toward environmental stimuli, and this must go hand in hand with a similar uncritical open-mindedness toward the ideas pressing forward from the preconscious and ultimately from the id. It can afford to be uncritical here because of the relaxing of the inner censorship when harmony is established for the moment between the three mental institutions, ego, superego, and id. All this, however, represents only the preliminary stage of the process—an essential one, it is true. It is followed by a far more critical stage during the final act of formulating the new theory of conception. In this stage there is a strict criticism of the incoming ideas combined with an exclusion or even oblivion of the outer world when outer stimuli are regarded as a hostile interference, as in the case of Archimedes they certainly were. The intense concentration of this stage may culminate in the state of trance mentioned earlier.

Now in the first stage the passive, almost self-effacing role of the ego in accepting the ideas pressing in from the preconscious must surely be associated with the more feminine aspect of the personality or as Freud preferred to term it, "the attitude of passive aims." It cannot be chance that so many words describing the process are taken from body analogies. The very word *inspiration* signifies a taking-in act on the part of the body. Poets often speak of being pregnant with their fancies, and the words *to conceive* and *to produce* equally apply to body activities. A writer can describe his mood as being in labor with an idea or actually giving birth to one. Furthermore, it is noteworthy how often, as constantly happened with Freud himself, the fomenting gestation of thought that precedes that final illumination is accompanied by just that kind of body discomfort that suggests the pains of labor. That women have more direct means of expressing this instinct would then account for the undeniable

fact of major creative thinking being almost a prerogative of the male sex. It is their substitute, the only one available to them, for the gift of body creation bestowed on women.

Conclusion

I will conclude by recalling your thoughts to the man in whose honor this article is written. It will probably be generations before all the implications of his ideas are fully worked out and the stimuli he provided for us fully acted on. Revolutions in thought such as he brought about do not happen very often in history, and it may well be long before another similar one takes place. We do not even know in what sphere of psychology to expect it; it might be one in the genetics of the mind or, on the other hand, in the field of social psychology. In the meantime what can we feel but gratitude toward the memory of a man who gave so richly and so generously? Truly one may well say with his favorite prince: "I shall not look upon his like again."

Icing Research Tunnel

Man-made ice storms are manufactured in the wind tunnel, shown on our cover this month, to test parts of high-performance jet models. The 9600-cubic-foot tunnel, which is part of Lockheed Aircraft Corporation's "weather works," is chilled by a 1,165,000-Btu-hour refrigeration system, or the equivalent of 776 home refrigerators. Misty spray and a mechanically created wind of hurricane force are added to duplicate flying conditions in ice-forming weather. The tunnel is 76½ feet long and 17 feet high. The test section measures 10 square feet. A bank of cooling coils arranged in a gridiron pattern 15 feet high and 9 feet 4 inches wide chills the onrushing air. Water droplets, controlled in sizes ranging from fine mist to large raindrops, are squirted into the tunnel to produce an icing cloud. The tunnel has a temperature range of $-40°F$ to $+150°F$ and maximum speed of more than 270 miles per hour.

At the time this photograph was taken the engineer was measuring impingement limits of ice on a portion of a modified C-130 wing section. An icing protection hot-air system was ducted into the leading edge. A series of tests was made to determine the anti-icing and de-icing effectiveness of the system. The wing shown here was allowed to build up an ice covering with the hot-air system inoperative in order to evaluate the distribution of icing severity. The protective system was subsequently activated, and pictures were taken at intervals until icing disappeared. The photograph was made by Charles W. Totten of North Hollywood, California.

Formation of the Elements

WILLIAM A. FOWLER

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GRAVITATION, which acts alike on apples, human beings, and heavenly bodies, has until now chained mankind to a minor planet of an average star. Even so, man has dared to ask questions not only concerning the nature of his own planetary prison, the earth, but also concerning the nature of the whole universe of planets, stars, and galaxies. In the not-too-distant future, man or his instruments, or both, may explore at first hand other astronomical objects. However, in attempting to answer these questions in the past, scientific man has relied on the observations that can be made on the light and radio waves, the cosmic-ray particles, and the meteorites that come to the earth from the solar system, the Milky Way, or still more remote astronomical systems. He has interpreted these observations in terms of the scientific laws of nature which he has been able to establish through terrestrial experimentation and theoretical studies. He has customarily postulated that these laws have universal validity both in space and time.

Central among the problems concerning the nature of the universe is the one of the origin of the elements. In their comprehensive review and analysis of the subject in 1950, R. A. Alpher and R. C. Herman (*1*) posed the problem through a quotation from Ben Jonson's *The Alchemist* (1610):

> Ay, for 'twere absurd
> To think that nature in the earth bred gold
> Perfect i' the instant: something went before.
> There must be remote matter.

The problem was actually appreciated by men more ancient than the rare Ben, but only in recent times have its exact nature and its possible solutions become at all clear. The clearest indication has arisen in the growing accumulation of observational data during the past century which shows that the relative abundances of the nuclear species of the elements are universal quantities and, indeed, that a cosmic abundance curve such as that shown in Fig. 1 can be constructed. The first complete tabulation of modern universal relative abundances was published by V. M. Goldschmidt (*2*) in 1937. Figure 1 is taken from an analysis made by Harrison Brown (*3*) in 1949 on the basis of his studies of meteoritic abundances and other evidence. The figure gives relative abundances as a function of the atomic weight of the nuclear species. Ten thousand atoms of silicon have been arbitrarily taken as the standard of comparison. H. E. Suess and H. C. Urey (*4*) have recently published a new tabulation that has a smaller scatter of points than the scatter shown in Fig. 1 but that is in substantial agreement with it. Special features of their new curve are already yielding refinements in our understanding of the detailed processes of element formation.

Why is the abundance curve plotted against atomic weight rather than atomic charge? Atoms consist of planetary electrons surrounding central, relatively massive nuclei. The properties of the atom depend on the number of its negatively charged electrons, which in turn is just equal to that necessary to neutralize the positive charge on the nucleus. Electrons come and go in atoms with relative ease in ordinary electrical and chemical processes. The nucleus is the characteristic and immutable part of an atom in such ordinary processes and, in fact, in all but certain violent laboratory or cosmic events. The origin of the elements resides in nuclear processes and not in chemical processes. The most fundamental property of a nucleus is its mass or atomic weight rather than its charge, and therefore the abundance curve of the figure is given in terms of atomic weight rather than atomic charge, by which elements are classified. In terms of the unit of mass used in modern physics, the atomic weights run from slightly more than unity (1.008) for the light hydrogen atom to almost exactly 209 for bismuth, which is the heaviest stable atom. Only mass 5 and mass 8 are missing among the stable elements. The naturally radioactive elements have atomic weight up to 238 for uranium. Atoms with atomic weights almost up to 260 have been produced artificially.

Sources of Data

On what sources of information is the universal, cosmic abundance curve based? The list of sources is imposing: terrestrial and meteoritic matter; light and radio waves from stars, galaxies, nebulae, and interstellar matter; reflected light from the planets; and finally even cosmic radiation. Terrestrial matter yields the proportions of the elements in the earth's crust, hydrosphere, and atmosphere. These proportions were certainly modified chemically in the process of formation of the earth. The volatile elements—hydrogen, helium, and the other inert noble gases—and carbon as methane, nitrogen as ammonia, oxygen as water vapor, and sulfur as hydrogen sulfide were lost during the process of formation, at least in part. Melting, crystallization, and erosion by water have changed the composition of the surface of the earth relative to the interior. Appropriate corrections for the original losses and for chemical fractionation over geologic time must be estimated. There is one important point about terrestrial samples. They yield in the mass spectrometer the proportions of the nuclear species or isotopes of a given element. It is primarily in this way that determinations of abundance in terms of atomic weight are possible. Relative isotopic abundances are in general independent of chemical fractionation, for all isotopes of the same element have almost precisely the same chemical properties. Suess and Urey have used relative isotopic abundances to establish the trend of their elemental abundance curve.

Information also comes from the free samples of matter from our solar system which we are able to study in the form of the meteorites that have penetrated our atmosphere and reached the surface of the earth. It is generally assumed that meteoritic matter has undergone less chemical fractionation than terrestrial material, and our abundance curve is weighted heavily by observations on meteoritic material.

Starlight brings with it the secret of the composition of the material in which it originates in the form of lines and bands in the spectrum that the astronomical spectroscopist obtains with a grating fed by the light from a telescope. The lines and bands are characteristic of the atoms or molecules that emit the light as a result of excitation by the high temperatures of stellar surfaces. They can be identified by subjecting atoms to similar excitation in laboratory arcs, sparks, and furnaces. Dark lines in a spectrum can also result from the absorption of light by atoms. In principle very simple, the identification of the characteristic spectrum of a given element and the determination of its abundance from the intensity of its lines is a very complicated and difficult matter because of the great welter of lines and bands that overlap and because of the varying responses of atoms to differing modes and degrees of excitation. Concerning starlight, we must note that it comes from the atoms in the stellar surface or "atmosphere" and not from the vast, interior bulk of a star. Starlight can tell us nothing directly about the composition of stellar interiors, and we must deduce this indirectly by using first principles of astrophysics and nuclear physics.

Radio waves from interstellar matter sing a song of hydrogen—and a very special one, too—and tell us, as we know from other observations, that most interstellar matter is hydrogen. Radio astronomy is a comparatively new science, and it may have much

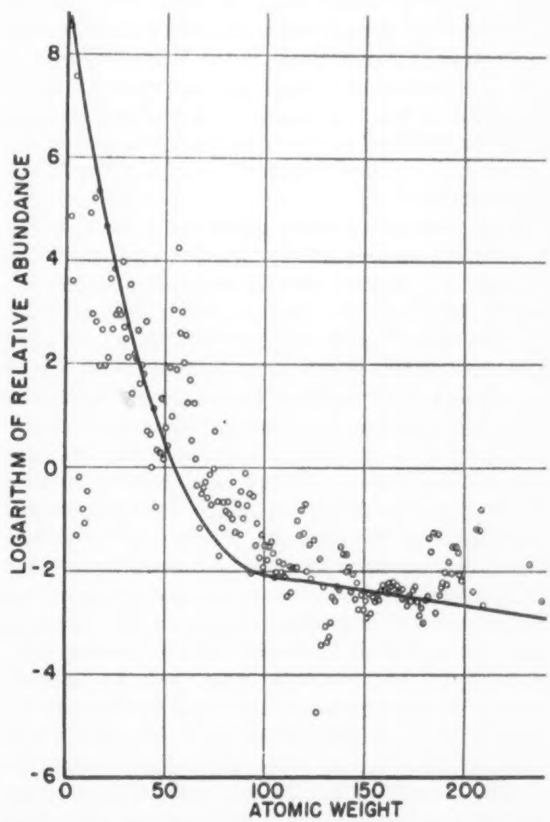

Fig. 1. Relative abundance of the nuclear species of the elements shown as a function of atomic weight according to data of Harrison Brown. Ten thousand atoms of silicon are arbitrarily taken as the standard of comparison. The abundance decreases rapidly up to atomic weight near 100 and is relatively constant thereafter. The iron group of elements stands out as a sharp peak near atomic weight 56. The low cluster of five points near atomic weight 10 are the rare isotopes of lithium, beryllium, and boron. The solid curve is the abundance expected on the basis of the solid curve for neutron-capture cross sections shown in Fig. 2. Note that the iron group does not seem to have been synthesized by neutron-capture processes alone. According to Hoyle, this group was produced by a great variety of nuclear reactions in equilibrium.

more to tell us, perhaps indirectly, about the abundance of the elements in the future.

We do not today understand completely the mechanism of acceleration of the very energetic cosmic ray particles that bombard the earth continually, but we can identify them experimentally as ions of certain elements by deflecting them in magnetic fields or by stopping them in photographic plates and particle counters. Once they have been identified and their relative numbers determined, we can say something about the relative abundance of the elements in the material in which these fast particles originated, whether it is in flares on the surfaces of stars, or in supernovae, or in interstellar space. Again, we may be fooled because these energetic particles suffer transmutations in collisions with other particles in the space they travel through to reach us and, most of all, in the blanketing atmosphere of our planet. It is obvious that the earth satellite will soon be the instrument of choice over balloons and rockets for attempts to ascertain the composition of the "primary" particles above our atmosphere.

Hence there are many clues and many pitfalls, and to follow successfully the first and avoid the second has involved the toil and wile of many scientific detectives. In a way, it is a pity that all this trouble should be had, just to establish, in each case, one of the points given in the prosaic figure to which I have referred. But all in all, it is satisfying and rewarding that all our methods of eavesdropping on nature come up with much the same story; from this story it has been possible to construct a reasonable picture of the universal, cosmic abundance of the elements. There are many individual exceptions to this averaged abundance, especially among the peculiar stars whose light reveals anomalous abundances of certain of the elements, and of this I shall have more to say in subsequent paragraphs. Moreover, we must beg the question of just what we mean by universal in this context. Our sample of matter is not truly universal if only because information from the solar system outweighs that from our galaxy, and that from our galaxy overshadows that from all others in the same sense. Furthermore, our sample has had its own particular history, and how typical and how average this history may have been are the questions that must be answered if we wish to dub our curve as truly universal.

Features of the Abundance Curve

The abundance curve has several features worthy of comment. In general, it drops off rapidly with increasing atomic weight to about $A = 100$, and then remains relatively constant thereafter. The most abundant element by far is hydrogen. Ninety-three percent of all atoms by number and 76 percent by weight are hydrogen atoms. Helium is next, some 7 percent by number and 23 percent by weight. The cluster of five low points near atomic weight 10 represents the five isotopes of lithium, beryllium, and boron. These elements are very rare indeed, adding up to only 3 parts in 1 billion (10^9) relative to hydrogen; on the basis of the theory of element formation in stars, we will see that this is quite reasonable. The light elements from carbon to sulfur total about 0.1 percent by number or 1 percent by weight. The smooth decrease of the abundance curve is sharply interrupted by the elements of the iron group, which stand out by a factor of about 10,000 over their immediate neighbors and constitute about 1 part in 100,000 by number or 1 part in 1000 by weight. Finally, the heavy elements add up to only 1 part in 100 million by number or 1 part in 1 million by weight. It is worth noting that the elements beyond helium are really quite rare in a relative sense. They constitute only a little more than 1 percent of the total mass in the universe.

It will perhaps not be taken amiss at this point if I enlarge upon the importance and interest of the universal abundance curve despite all questions concerning its validity. It is indeed the product and the result of the history of our galaxy as best we know it, and thus it is in turn one of our most powerful clues to the nature of that history. Cosmic events shaped this curve, and from it we can learn of cosmology and of stellar evolution and of all the "grandscale" subjects of modern science.

Mechanisms of Nuclear Synthesis

If we take it, then, that the facts are in, it can be argued from here on that any theory of the origin of the nuclei of the elements must reveal a recipe, which, if followed, would brew the mixture of the nuclei in their universal proportions. There are probably still those who would claim that these proportions were established in the original genesis at a date quite accurately given by Archbishop Ussher (*5*) as 4004 B.C. All current scientific theories adopt a somewhat more extended time scale and attempt to limit the genesis to the less dramatic production of only the common building blocks of the nuclei. Regardless of the circumstances and the processes that are postulated, these theories are based in common on the fact that modern nuclear research has shown that all nuclei consist of two fundamental building blocks, protons and neutrons, which in this context are called nucleons. The mod-

ern discoveries modify in detail but support in general the hypothesis of the Englishman, William Prout, who suggested as early as 1815 that the atoms of all elements are made up of atoms of hydrogen (*6*).

E. C. Watson of the California Institute of Technology found the references to Prouts' original articles and pointed out that Prout did not sign either of these articles. This was confirmed by a perusal of the index of the *Annals of Philosophy* for 1815, which yielded only the following entry under Prouts' name: "Prout, Dr. experiments, by, on the sap of the vine, 109–on the excrement of the boa constrictor, 413–on the liquor amnii of a cow, 416–on the ink of the cuttle fish, 417." There is nothing on the hypothesis that the atoms of all elements were made up of atoms of hydrogen. However, a short search located the two articles with this succinct and modest claim in the second of the two: "If the views we have ventured to advance be correct, we may almost consider the πρώτη ὕλη of the ancients to be realised in hydrogen; an opinion, by the by, not altogether new."

The proton is the nucleus of the simplest of all atoms, those of light hydrogen. Its positive charge is accurately known to be equal but opposite to that of the single negative electron with which it forms the hydrogen atom. The proton is some 1840 times more massive than its companion electron. What is important to the argument at this point is that all nuclei consist in part of protons and in fact derive their positive charge from them. This we know because when nuclei are made to collide with each other in the laboratory at greater than ordinary energies, protons are produced. In fact, the proton was one of the particles produced in the first successful transmutation of the elements by Lord Rutherford in 1919 (*7*). In what follows, I shall designate the proton by H^1, a symbol borrowed from chemistry, where it designates the light hydrogen atom. Nuclear processes, in the laboratory or in element synthesis, are always followed by appropriate rearrangements of the atomic electrons, and hence we can discuss the processes in terms of nuclei or atoms without confusion.

The other building block of nuclei, the neutron, was first produced in nuclear reactions in 1932 by Chadwick (*8*). It was found to be only slightly heavier than the proton and to be electrically neutral—hence the name, *neutron*. The neutron is designated by the symbol n^1. It does not exist in the free state in nature, and when it is produced in the laboratory, it is usually absorbed by another nucleus, but if it is not, it decays spontaneously into a proton and electron.

In nuclei, neutrons are apparently stable, and all stable nuclei consist of roughly equal numbers of neutrons and protons. There is some excess of neutrons in the heavier species. The oxygen nucleus of atomic weight 16, designated by O^{16}, consists of eight protons and eight neutrons, for example. The isotope of uranium, U^{238}, consists of 92 protons and 146 neutrons. Unstable nuclei that can be produced in the laboratory have either too many neutrons or too many protons relative to the stable form of the same atomic weight. In forms with an excess of neutrons, the neutrons change to protons with the emission of negative electrons until the stable proportions are reached. Thus C^{14} (carbon-14, with six protons and eight neutrons) decays with the emission of an electron to stable N^{14} (nitrogen-14, with seven protons and seven neutrons). Similarly, in those forms with an excess of protons, the protons change to neutrons with the emission of positive electrons or positrons. Thus O^{14} (oxygen-14, with eight protons and six neutrons) decays with the emission of a positron to N^{14}. These processes are called negative and positive beta decay, respectively. The term *beta* is used because electron emission was the second type of natural radioactivity to be identified. It is now believed that neutrino emission also occurs in the beta-decay process, and since neutrinos interact only weakly with other forms of matter, some energy is lost in this manner. Under most circumstances in element-building processes, this loss is small and can be neglected.

The existence of positive beta decay reduces in some measure the apparent difference in the properties of the two fundamental building blocks. Under some circumstances, neutrons are unstable; under others, protons are unstable. In the special case of the free state, it is the neutron that is unstable. All instabilities, however, lead only to the stable proportions of neutrons and protons and do not change their total number. Taken together as nucleons, they are immutable.

The last statement is in fact not entirely true. It has been recently found at Berkeley (*9*) that at very high energies protons with both positive and negative charges can be produced in the laboratory, and that the negative protons seek out and annihilate positive protons in ordinary matter. These extremely high-energy processes will certainly prove in time to be of interest in connection with cosmic events, but we know even now that only rare cosmic processes reach the necessary energies and that the origin of the elements resides in more probable events at more modest energies. In point of fact, we do not completely understand the nature of protons and neutrons when they are inside nuclei. What we do know is that over a wide range of laboratory energies, not too low and not too high,

nuclear reactions involving the disappearance of some nuclei and the appearance of others can be described as the shuffling and reshuffling of protons and neutrons into the variety of nucleonic packs that we call nuclei. The total number of protons plus neutrons does not change.

We need to consider one more point having to do with the relative stability of the various stable forms of nuclei. I use the term *relative stability* here in the sense that the more energy that is required to break up or transmute a nucleus, the more stable the nucleus is. Both from mass spectroscopy and from the energies of nuclear reactions, we know that neutrons and protons are most tightly bound together in the form of the nuclei of the iron group of elements and that the further we go in atomic weight away from this group in either direction, the less stable the nuclei become. This means that the fusion of light nuclei results in the formation of more stable nuclei and in the release of energy and that the fission of the heavy nuclei also results in the release of energy. The fusion of hydrogen into helium lies at one extreme, and the fission of uranium into two roughly equal parts lies at the other. Cosmic processes tend to release energy in the form of radiation or kinetic energy and will thus lead in general to the relatively more stable nuclear forms except under extreme circumstances of high temperature and density.

All nuclear particles except the neutron are positively charged and thus repel each other. For a nuclear transmutation to take place, the nuclei must come close together despite their mutual electric repulsions. They must have some initial energy of relative motion in order to overcome or tunnel through the repulsion and to "trigger" the nuclear reactions. In the laboratory, one type of nuclear particle is accelerated to high velocity in electrostatic accelerators, cyclotrons, synchrotrons, and so forth and allowed to impinge on a stationary "target" consisting of nuclei of a second type.

When we come to discuss nuclear processes in stars, we shall see that the high temperature in the interior of stars means that the nuclei have large random velocities with respect to each other and that, in head-on collisions, nuclear reactions take place. These head-on collisions are very infrequent, and thus the nuclear energy is released steadily rather than catastrophically. It is the electric repulsion between "like" charges which essentially controls thermonuclear reaction rates over the billions of years during which stars shine steadily and uniformly. Neutrons do react very rapidly, as we have learned dramatically from the atomic and hydrogen bomb. However, they are not stable in the free state and they must be produced in nuclear reactions between charged particles that do have a built-in control mechanism, as we have noted.

With this picture of the structure and interactions of the nuclei of the elements in mind, it is simple and natural to attempt to understand the origin of the elements in a synthesis or build-up starting with one or the other or both of the fundamental building blocks. The point of view places in a separate category questions concerning the creation of matter in the form of the primary nucleons. Only men of strong convictions, religious or scientific, Ussher or Hoyle, have the courage to approach the problem of the creation. This is a problem of the utmost significance, but because of lack of space, I shall sidestep it and stick to the previous problem, which can now be phrased thus: Given protons or neutrons, when, where, and how have the heavier elements been synthesized? Whatever our answer, we see from the abundances discussed in previous paragraphs that the process of synthesis need not be overworked: only 1 percent of the observable mass has been processed beyond helium.

The Four Theories

There are four theories or points of view concerning the origin of the elements: the equilibrium theory, polyneutron fission, nonequilibrium neutron capture, and synthesis in stars and supernovae. Consideration will now be given to each of these theories in turn. Because of my predilections, a perhaps unwarranted emphasis will be accorded the last of these.

Equilibrium theories, notably in the hands of Otto Klein (*10*) of Sweden, have assumed an early, prestellar state of the universe in which nuclear interactions were so profuse that all the nuclei were produced once and for all in their equilibrium concentrations. In general, these concentrations depend on the temperature and density of the prestellar system, as well as on the relative stability of the nuclei. Obviously, it must be assumed that there exist all the necessary nuclear reactions to establish the equilibrium, but the details of the reactions need not be known; only the stability of the reactants needs to be known.

Nuclei are really quite stable, and for equilibrium to be established through nuclear reactions in a reasonable length of time in bulk matter requires high temperatures of the order of 10 billion degrees and high densities of the order of 100 million times that of ordinary matter. Even with such extreme assumptions, it has been found that no single set of physical conditions would have simultaneously given rise to the correct relative abundance of the

light and the heavy elements, and it has been necessary to postulate at least two distinct epochs in the early evolution of the universe. There is also the difficult question concerning how the nuclear equilibrium was "frozen-in" at high temperatures when some time must be allotted for the cooling off of the prestellar system. Because of the seriousness of these difficulties, the equilibrium theory does not have general acceptance, but it does have important applications in a restricted sense, as we shall see in the subsequent discussion of the synthesis of the elements in stars.

The polyneutron fission model of Maria Mayer and Edward Teller (*11*) postulates a primordial "cold" nuclear fluid consisting primarily of neutrons. The polyneutrons are taken to be much heavier than the nuclei now known, but it is assumed that they break up spontaneously by fission processes similar to those induced in uranium by neutron irradiation in nuclear reactors and in atomic weapons. Spontaneous fission is observed to be the fate of the very heaviest transuranic elements that can be produced in the laboratory. The fission of the polyneutron nuclei yields highly excited fragments with a large excess of neutrons. These fragments undergo neutron evaporation and electron decay and finally become the present heavy nuclei. The theory has had some success in predicting observed isotopic abundances for the elements from gadolinium to platinum. However, the theory does not describe at all the production of the light elements, and Mayer and Teller suggest that these were produced by thermonuclear processes involving principally protons. The role of a cold primordial nuclear fluid in the history of our universe has never been elaborated, nor has it been checked in any detail against astronomical observations.

Perhaps the most widely held theory of element synthesis is that involving nonequilibrium neutron capture. This theory is principally the result of the work of George Gamow (*12*) and his collaborators (*1*). It is based on the fact observed in the laboratory that practically all nuclei will capture or absorb individual neutrons when they are irradiated by a neutron beam, and thus will increase their atomic weight by one unit. The product nuclei are stable, or else they emit a negative electron to form the appropriate stable nucleus. Thus a mechanism exists by which heavy nuclei can be synthesized from lighter ones by a succession of neutron captures interspersed where necessary by electron decay.

To depict the circumstances of the origin of the elements by neutron capture, Gamow has appealed to the astronomical evidence for the expanding universe. We argue from the red shift of their light that distant galaxies are moving away from us with velocities that have so far been measured up to one-fifth the velocity of light and that, the more distant the galaxy, the greater its velocity of recession. The simplest explanation of these observations is to postulate a primordial "big bang" in which all the matter of our universe was ejected with high velocity from a common region; the galaxies whose matter received the greatest velocities relative to that of our own are now the most distant from us. The magnitude of the velocities as deduced from the red shifts and from the distances to the galaxies as calculated from their apparent brightness fix the time of the creation as some 5 billion years ago on this point of view.

Gamow opines that in the early stages of the expansion the density of radiation and matter was very great indeed and that under these circumstances neutrons rather than protons were the stable constituents of nucleonic matter. One can think of electrons as being compressed into the protons in a reversal of the electron decay observed for the neutron in the free state at low density. And so, Gamow postulates a huge "neutron ball" that actually was in the beginning mostly radiation and that promptly began to expand because of its great internal energy. This was the start of the expansion of our universe which we now observe. After some expansion, certain of the neutrons decay to protons, which find themselves in the enormous flux of the remaining neutrons. A proton captures a neutron to form the deuteron, the hydrogen isotope of mass 2, which is designated by H^2 or D^2. Some of the deuterons capture another neutron to form the triton or hydrogen-3 nucleus, H^3 or T^3, which decays to the helium-3 nucleus, He^3, by emission of a negative electron. The He^3 nucleus captures a neutron to form the helium-4 nucleus, He^4.

These processes are typical of the succession of neutron captures and electron decays that synthesized all the nuclei of the elements as the universe expanded and the primordial neutrons decayed or were captured. Actually, all of element building is thought to have taken place in a matter of a few minutes quite early in the expansion when the matter density had dropped to 10^{-7} gram per cubic centimeter, the total density of radiation and matter was 1 gram per cubic centimeter, and the temperature was 10^9 degrees Kelvin. These conditions were assumed as most favorable for heavy-element synthesis by neutron capture. This picture of the creation and the element building, followed rapidly by star and planet formation, is the one that is most consistent with traditional religious beliefs, and it has had a widespread and perhaps justified popular appeal for this reason.

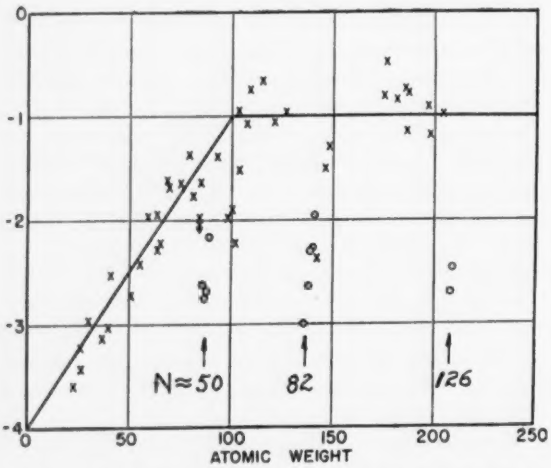

Fig. 2. The target area or cross section of a nucleus for neutron capture shown as a function of atomic weight according to data of D. J. Hughes and his collaborators. Cross sections are measured in barns (10^{-24} square centimeter). The heavier nuclei have larger target areas and thus capture neutrons more readily. As a consequence, their number need not be so great in a continuous chain of neutron-capture processes, and this is indeed found to be the case in general, as illustrated in Fig. 1. The "magic number" nuclei with closed neutron shells at neutron numbers (N) equal to 50, 82, and 126 are seen to have anomalously small cross sections.

The most conspicuous scientific success of the neutron-capture picture is the correlation that can be made between abundances and the target cross sections of the various nuclei for neutron capture when neutrons are fired at them in the laboratory. The cross-sectional target area of a nucleus for neutron capture determines the rate at which neutrons will be captured by this nucleus in the early build-up process. These cross sections can be measured in the reactor or laboratory at the present time, and the measured results of D. J. Hughes (*13*) and his collaborators at Brookhaven National Laboratory for cross sections in terms of the atomic weight of the target nuclei are shown in Fig. 2. The reactor neutrons employed by Hughes are thought to have much the same energy distribution as the neutrons in the primordial neutron ball.

Now, in any chain of events such as the successive neutron capture, there is an important consequence of the very continuity of the over-all process. For example, consider nuclei of a type that have small target cross sections and thus capture neutrons slowly. These nuclei will be built up to a relatively large abundance because they do not change rapidly to the nuclei of next highest atomic weight. On the other hand, nuclei with large cross sections which capture neutrons rapidly will not need to be abundant in order to keep the chain going. Thus, continuity demands an inverse relationship between the neutron-capture cross section and the abundance produced in a succession of neutron captures. An examination of Figs. 1 and 2 shows that this is indeed the case. The experimental cross-section curve rises rapidly with atomic weight until $A = 100$, and then flattens off, and on Gamow's theory this is why the abundance curve drops rapidly with atomic weight to $A = 100$ and then remains relatively constant. In fact, the solid curve in Fig. 1 is the one to be expected on the basis of the solid curve passed smoothly through the points of Fig. 2.

There is even considerable correlation for some of the fluctuations observed. The so-called "magic" nuclei with complete shells of neutrons which close at neutron numbers 50, 82, and 126 are particularly stable and have correspondingly small cross sections for adding additional neutrons by capture. Following the inverse relationship dictated by continuity, they are indeed found to be relatively more abundant than their neighbors with roughly the same atomic weight. It is perhaps not unfair for me to emphasize at this point that this agreement will hold in general for neutron-capture synthesis under any circumstances and is not to be taken as direct proof of the "big bang" theory of creation. We shall see that neutron capture can also occur in stars.

We must now reluctantly consider the difficulties with the primeval neutron capture theory. These have been very completely discussed by Alpher and Herman (*1*) in their detailed elaboration of Gamow's point of view and their review of the other theories in 1950. There is general but not detailed agreement point-for-point in the inverse relationship between capture cross section and abundances. The peak at the iron group is not at all to be expected on the basis of the cross sections. Certain "shielded" nuclei that exist in nature cannot be produced at all in the chain of rapid neutron-capture and electron-decay events. These nuclei are shielded by their stable isobars, which terminate the electron decay before the nuclei in question are produced.

Perhaps the most serious problem of all has to do with the fact mentioned previously that there are no stable atoms with mass 5 or mass 8. When He^4 is bombarded by neutrons in the laboratory, it forms a mass 5 nucleus, He^5, but only for an extremely short period, the He^5 breaking up practically immediately into He^4 and a neutron. There is no stable form of mass 5, and thus no build-up through and beyond this mass is possible by neutron capture alone; the synthesis stops when all the hydrogen has been turned into helium in the form

of He^4. Even if it proceeded beyond mass 5, the synthesis would be stopped at mass 8. An isotope of beryllium of mass 8, Be^8, would eventually be produced in the chain. This isotope has been produced momentarily in the laboratory, and its properties have been extensively studied. It breaks up or fissions into two equal parts—that is into two He^4 nuclei—with a relatively small but definitely positive energy release. Modern techniques have even established its lifetime as a 10^{-15} second, but that is a long and fascinating story that deserves its own special telling. Thus neutron capture starting with hydrogen can be shown experimentally to build up only to helium, which is a disappointing showing in view of the great promise and philosophic attractiveness of the primordial neutron-capture theory.

Fermi and Turkevich (*14*) made a detailed attempt to save the primeval theory of nucleogenesis by introducing into the calculations reactions involving the charged particles, protons, deuterons, tritons, He^3, and He^4 that result from neutron decay and capture. They concluded that these reactions would not suffice to start heavy-element synthesis under the conditions of density and temperature that are commonly considered to have held during the early stages of the expanding universe.

A basic difficulty with primeval synthesis involving charged-particle reactions during early stages of the universal expansion is just the expansion itself. As a result of the expansion, the temperature and density of matter are decreasing with time. Element synthesis involves the production of nuclear forms with increasing charge and increasing electric barriers. To overcome these increasing barriers, nuclear enounters of greater energy and greater frequency are required. Thus, the temperature and density should in general increase with time rather than decrease, as they do in the expanding universe. We shall now turn to a point of view in which this fundamental condition is met. It is one in which neutron capture plays an important role, but it does so on a celestial stage on which other events take place in many different scenes and on which the stark and majestic drama of primeval synthesis is lost. "All the world's a stage" for element synthesis in the last of the four theories.

Synthesis of Elements in Stars

The synthesis of the elements in stars is a point of view that has been championed most extensively by Fred Hoyle (*15*), fellow of St. John's College, Cambridge University. Recent significant advances in understanding of the nuclear processes involved have been made by E. E. Salpeter (*16*) of Cornell University and by A. G. W. Cameron (*17*) of Chalk River, Canada, as well as by Hoyle. Experimental research has been done on these processes in the Kellogg Radiation Laboratory at California Institute of Technology under the direction of C. C. Lauritsen and me, and in many other laboratories. The astrophysical implications have been stressed by J. L. Greenstein (*18*) of California Institute of Technology, by Martin Schwarzschild (*19*) of Princeton University, and by G. R. and E. Margaret Burbidge (*20*) of Cambridge, England. The reader is referred to the report (*21*) of the international colloquium on "Nuclear processes in stars" which was held at Liege, Belgium, in September 1953 for an extensive list of investigators who are working in this field of astrophysics.

This description of nucleosynthesis in stars starts from the well-established facts that the source of energy in stars is reactions among nuclei and that nuclear reactions which release energy must involve the transmutation of nuclei of low stability into nuclei of great stability. Fusion from hydrogen up to the most stable nuclei in the iron group and neutron capture thereafter will be expected to play an important part. This point of view involves two vastly different time intervals: stars that shine for 10^{17} seconds or more do so with energy from nuclear reactions that individually occur in some cases in less than 10^{-17} second.

We begin (if we must begin) with hydrogen atoms (or with neutrons that decay into protons and electrons that form hydrogen atoms) in the form of a cold, dilute, but turbulent gas. This could have originated in a primeval, explosive phase of the expanding universe in which nucleogenesis may or may not have taken place. The simplest assumption is that it did not take place. However, even if it did, the primordial abundance distribution will have been, at least in part, modified by nuclear processes in stars. Interest in the primeval event becomes largely academic, for it happened at most but once, and some and perhaps all evidence of its occurrence has been obliterated by subsequent events.

Part of the turbulent hydrogen gas condenses into stars under the influence of gravitational forces. As the stellar material contracts, the interior becomes dense and very hot from the conversion of gravitational potential energy into kinetic energy. Under these conditions, nuclear reactions start, and the star is stabilized as the nuclear energy sources replace that from gravitational contraction. As successive nuclear processes take place, the stars are said to evolve, and it is essential in the theory of stellar synthesis that instabilities arise that return the transmuted material to interstellar space and mix it with the primeval hydrogen so that it is

available for condensation into second- and later-generation stars. The general state of affairs in this "equilibrium" between stars and the interstellar gas and dust is illustrated in Fig. 3.

The most spectacular instabilities in stars result in the novae and supernovae that are observed to flare up suddenly and then die away in brightness. This process results in an amorphous mass of material such as the Crab nebula, which is now located in the same region in the sky where Chinese astronomers (*22*) observed a supernova explosion in A. D. 1054. Other stars, including even our sun, slowly eject matter into space and radiate light as well. White dwarfs are known to be much less massive than the stars from which they evolved. Quantitative calculations show that the rate of these transfer mechanisms is such that they are probably capable of introducing the observed small amounts of the synthesized elements into our cosmic sample.

The reverse process, the formation of stars, also has substantial observational confirmation. There are stars in the heavens so bright for their known mass that even nuclear processes cannot have kept them shining for much more than 10 million years. Our sun has been shining steadily for 5 billion years and will do so for at least as long before its internal structure and external appearance change. The bright stars are "young" stars, and since they occur most frequently in regions observed to be populated with relatively large amounts of gas, it is reasonable to assume that they condensed from interstellar material. In fact, in regions of no gas and dust, there are few great bright stars: only the slow burners from the original and succeeding condensations that cleaned up the vicinity remain in these regions.

The process of gravitational contraction of a protostar containing only hydrogen leads to a temperature rise in the interior, and the thermonuclear fusion of four hydrogen atoms into one helium atom begins. The fusion of hydrogen is now firmly established as the source of energy in the great majority of stars that are said to belong to the "main sequence" because of the regularity in the relationship between their brightness and their color, the bright ones appearing blue in color, the dim ones being somewhat redder. Among the first to suggest this source of stellar energies was Eddington (*23*) in 1920, who based his suggestion on the observation of Aston (*24*). Aston had shown with the mass spectrograph that four hydrogen atoms were about 0.7 percent heavier than one helium atom. By Einstein's (*25*) celebrated relation, $E = Mc^2$, even the annihilation of this small fraction of the mass leads to a large energy release because of the high value of the velocity of light, which occurs squared in the equation. Thus, without a very great change in its mass, a star can shine on nuclear energy for considerable periods of time. Eddington was supported in his contention by knowledge of the fact that Lord Rutherford (*7*) in 1919 had actually produced nuclear transmutations in the Cavendish Laboratory. In promulgating his point of view to the British Association for the Advancement of Science at Cardiff in 1920, Eddington included the following remark: ". . . and what is possible in the Cavendish Laboratory may not be too difficult in the Sun."

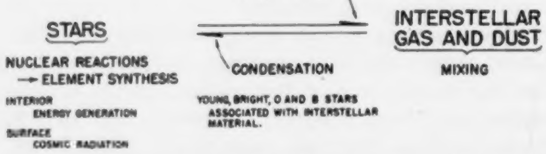

Fig. 3. Transfer of material between stars and interstellar gas and dust. Synthesis of elements occurs in the stars, and mixing to yield the relative cosmic abundance of the elements occurs in interstellar space. Mechanisms for the transfer as observed astronomically are indicated.

Eddington was right! In 1928 Atkinson and Houtermans (*26*) calculated the rate of energy generation in stars on the basis that the source of energy was exothermic nuclear reactions between charged particles and nuclei. They investigated in particular the fusion of hydrogen into helium through cyclic processes involving the light nuclei, which they did not describe in detail. They based their calculations on the discovery, independently made by Gamow (*27*) and by Condon and Gurney (*28*) that quantum-mechanical electric barriers could be penetrated without the large energies required to go over the top of the classical barrier.

In 1932 Cockcroft and Walton (*29*) showed experimentally that an exothermic reaction occurred between protons and the lithium-7, Li^7, nucleus with the emission of two alpha-particles. Independently in Pasadena, Berkeley, Washington, and Cambridge it was shown that many nuclei, C^{12} being the first, captured protons (*30*) with the emission of gamma radiation. These reactions were induced with bombarding proton energies well below those required to surmount the classical electric barrier. Gamow and Teller (*31*) added resonance effects to the calculation of stellar energy generation in 1938. In this same year, Hans Bethe and Charles Critchfield (*32*) elucidated a chain of reactions starting with pure hydrogen which led ultimately to helium, and Bethe (*33*) and von Weizsächer (*34*) independently suggested a cyclic conversion of hydrogen into helium through the catalytic action of the two stable isotopes of carbon and

the two of nitrogen. In a now classical paper (33), Bethe in 1939 gave quantitative calculations on a remarkably complete list of nuclear processes based on the best experimental evidence available at the time. We now turn to a discussion of the fusion of helium from pure hydrogen.

When the central temperature of a star condensing from hydrogen reaches about 5 million degrees, the protons are in sufficiently rapid relative motion so that when two protons collide they can form the mass 2 deuteron and a positron with the release of energy. The positron soon annihilates an electron, and further energy is released. The deuteron moves about in the ordinary hydrogen until it collides with a proton to form a helium nucleus of mass 3, He^3. The He^3 does not interact with protons, so its concentration builds up until pairs of He^3 nuclei collide with the production of the alpha-particle, He^4, and two protons. This fast process, which was first suggested independently by C. C. Lauritsen (35) and by E. Schatzman (36), has been demonstrated in the laboratory by W. M. Good, W. E. Kunz, and C. D. Moak (37) at Oak Ridge. These processes are indicated graphically in Fig. 4. The over-all result is that six protons interact to produce one alpha particle and two positrons with two protons left over. When the electronic readjustments are completed, the final result is that four hydrogen atoms have been converted into one helium atom.

The chain of reactions shown in Fig. 4 is the primary mechanism by which element synthesis is initiated, using hydrogen atoms as universal building blocks. No other element is needed in the beginning. It is true that the first step of the process, the formation of the deuteron, occurs so rarely in the interaction of protons that it has not been observed in the laboratory. However, theoretical analysis based on analogous processes, which have been observed, makes it possible to predict that the reaction will take place abundantly at the high density and temperature of stellar interiors.

At the formation of the deuteron, the emission of the positron is accompanied by the emission of a neutrino, a weakly interacting particle without mass or charge first postulated by Pauli (38) as necessary to conserve energy, linear momentum, and angular momentum in beta decay. Fermi's successful theory of beta decay (39) assumes the emission of neutrinos. The neutrinos are so weakly interacting that the great majority of those produced actually escape from a star. However, the amount of kinetic energy that they carry away is only a few percent of the total energy released in the thermonuclear process. Even though their interaction with matter is very small, the interaction of neutrinos from the Hanford and Savannah River reactors with hydrogen has been recently detected by Cowan and Reines (40) of Los Alamos. This discovery of the free neutrino leads to considerable confidence in the theoretical calculations on the primary process by which nucleosynthesis from pure hydrogen is started.

The conversion of hydrogen into helium occurs in the core of the star because the temperature and density are highest there. Judging from astrophysical observations, it appears that the reaction product, helium, is mixed with the outer envelope, still hydrogen, with extreme difficulty. Thus a core of helium develops and gradually increases in size as more and more hydrogen is converted. Helium nuclei are double charged, while protons are singly charged, and because of the greater electric repulsion, helium nuclei do not interact at the temperature at which they were formed from the hydrogen nuclei. Thus the nuclear hydrogen furnace goes out for lack of fuel, and one would expect from ordinary experience with furnaces that the temperature would drop. But this is not at all the case in stars because of their great potential gravitational energy. The helium "ash" in the core begins to contract, and its temperature rises as gravitational energy is converted into kinetic energy.

This "anomalous" behavior of stars is not all pure conjecture, for the sudden rise in temperature of the core also heats up the envelope, which expands enormously and increases the surface area of the star. The increased area means that energy can be radiated at a lower surface temperature, and thus

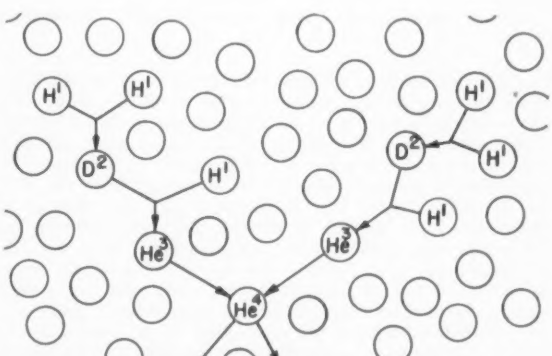

Fig. 4. Fusion of ordinary hydrogen as in the sun. The primary step in the synthesis of the elements from hydrogen involves the conversion of four hydrogen atoms into one helium atom. The nuclear processes by which this occurs are illustrated and are discussed in detail in the text. These processes are the source of energy in our sun and the cooler stars of the main sequence.

the surface reddens in color. Large in area and red in color, these stars are aptly called the "red giants" by astronomers. Their existence constitutes evidence that stars which have consumed a substantial amount of their interior hydrogen have developed hot cores of helium. Theoretical calculations have

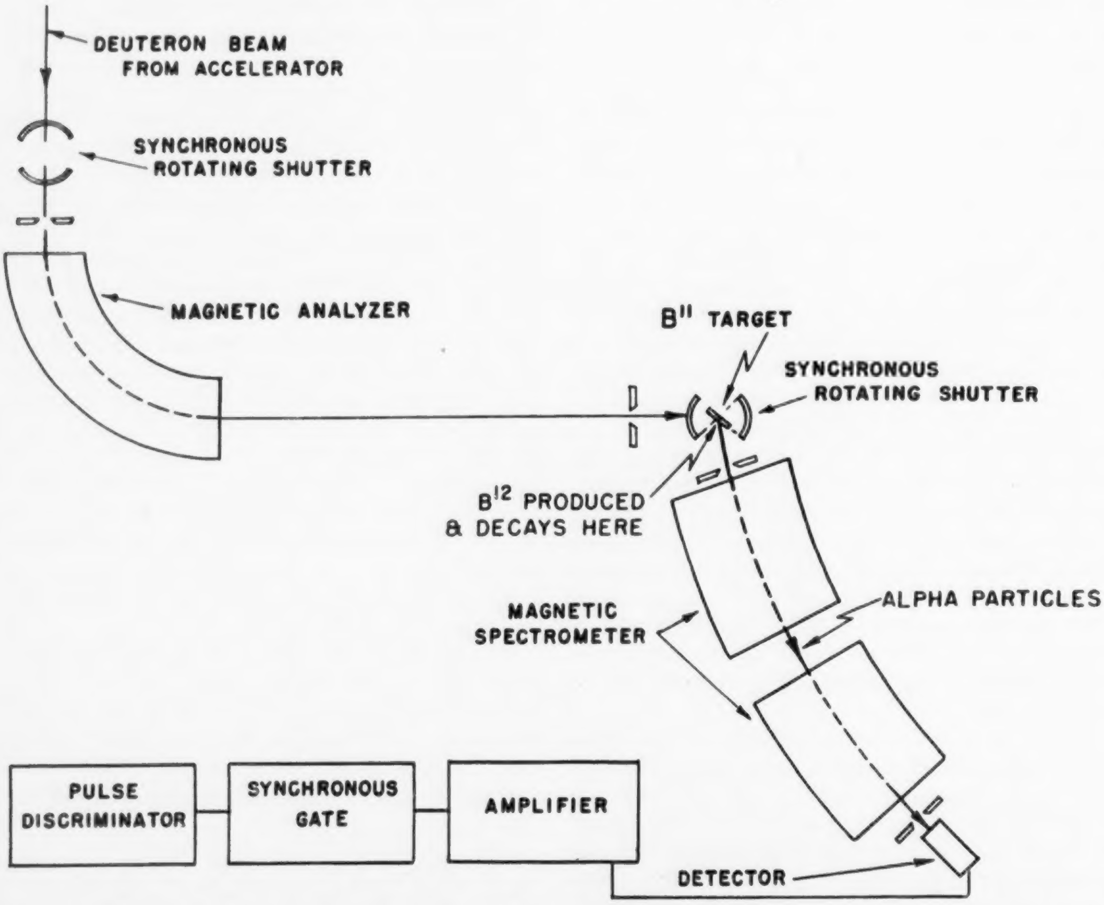

Fig. 5. The purpose of the experiment is to produce and study the excited state of the nucleus C^{12} that serves as an intermediate stage in the formation of stable carbon from three helium nuclei in red giant stars. The excited carbon is produced by bombarding a target of B^{11} with high-energy deuterons, the nuclei of heavy hydrogen. This figure shows the details of the experiment schematically. The deuterons are accelerated to an energy of 2 million electron volts in an electrostatic accelerator. The deuteron beam first passes through a rotating shutter synchronized with a similar shutter rotating about the B^{11} target. Both shutters are shown in the "closed" position in the diagram. When rotated through 90°, the shutters permit the deuteron beam to pass through the magnetic analyzer, which is used to control the beam energy, and to strike the B^{11} target. The B^{11} is transmuted into B^{12} under bombardment by the deuterons with the emission of protons. The B^{12} is radioactive with a half-life of 0.022 second. It decays with the emission of an electron and a neutrino into C^{12}. Most of the time it decays to the ground state of C^{12}, and this was discovered in the Kellogg Laboratory almost 20 years ago. What the present experiments have found is that about 1 percent of the time B^{12} decays to an excited state at 7.65-million-electron-volt excitation in C^{12}. This state breaks up into three alpha particles or He^4 nuclei in a very small fraction of a second (we estimate 10^{-15} second). The alpha particles pass through the magnetic spectrometer, which makes it possible for us to determine their momentum and energy. They then impinge on a cesium iodide scintillation counter or detector. The light flash that they make in the scintillator is converted into an electric pulse in a photoelectric tube. This pulse is amplified and counted as the final step in the experiment. When the second shutter opens the target to the incident beam, it at the same time cuts off the spectrometer and detector from the alpha particles and from the much more numerous protons and scattered deuterons that emerge from the target during bombardment. On rotating to the position shown in the diagram, the shutter cuts off the incident beam and allows the alpha particles from the decaying B^{12}, via the excited C^{12}, to enter the spectrometer and be detected without interference from the prompt reaction products. Only the delay time in the radioactivity of the B^{12} makes the experiment possible. The shutters are driven by two 1800-revolution-per-minute synchronous motors, and so the experiment is performed by alternately bombarding the target and observing 60 times a second. The energy spectrum of the alpha particles is obtained by making runs with different values of the magnetic field. From this spectrum, the energy of the C^{12} excited state can be calculated.

indicated that the core temperatures rise to somewhat more than 100 million degrees.

What happens next was the Gordian knot of element synthesis until just recently. Two helium nuclei on interacting might be expected to form the beryllium nucleus of charge 4 and mass 8, Be^8. However, as we noted previously, no nucleus of mass 8 exists in nature, and from this one can infer that it must be unstable. In 1939 E. Glückauf and F. A. Paneth (*41*) showed that gamma-ray irradiation of Be^9 resulted in a neutron and two alpha particles rather than a neutron and Be^8. Be^8 was presumably produced, but almost instantaneously disintegrated into two alpha particles. Shortly after World War II, this was confirmed in quantitative measurements of the Be^8-decay energy by Arthur Hemmendinger (*42*) at Los Alamos and by A. V. Tollestrup (*43*) at California Institute of Technology. In both laboratories, it was found that when Be^8 was produced artificially in nuclear reactions it promptly broke up into two alpha particles. However, the energy of breakup was found to be relatively small. With this last fact in mind, E. E. Salpeter (*16*) then pointed out that although hot interacting helium will not produce a stable Be^8 nucleus, it will produce a small but real concentration of Be^8 as a result of equilibrium between the formation and breakup processes. Now light, stable nuclei are found in the laboratory to capture alpha particles with the emission of energy in the form of gamma radiation. Salpeter pointed out that the Be^8 should behave similarly and that if, after its formation from two alpha particles, it collided with a third, the well-known stable carbon nucleus, C^{12}, of charge 6 and mass 12 should be formed. Because of the low equilibrium concentration of the Be^8, about 1 part in 10 billion at 100 million degrees, Fred Hoyle (*15*) emphasized that the Be^8 capture process had better be a very rapid one or a "resonant" reaction in nuclear parlance. At California Institute of Technology, in experiments conducted in the Kellogg Radiation Laboratory by research teams working with W. Whaling (*44*) and T. Lauritsen (*45*), we have been able to show that this is the case. Our methods have been perforce indirect ones, for we do not have a Be^8 target to bombard in the laboratory. The stable form of beryllium is Be^9. The artificially produced Be^8 decays in a very small fraction of a second. What we have been able to do is to show that there exists an excited state of the C^{12} nucleus with almost the exact energy of excitation and other properties which Hoyle predicted that it must have in order to serve as a thermal resonance for the formation of C^{12} from Be^8 and He^4 in stars.

We produce this excited form of carbon C^{12*} (the asterisk designates excitation) by first accelerating deuterons to high energy in an electrostatic accelerator and then by allowing the deuterons to impinge on a target of boron. The experimental arrangement is shown in Fig. 5. Nuclear transmutations result in the production of the C^{12*}, which promptly disintegrates into three low-energy alpha particles whose energy spectrum is shown in Fig. 6. We are able to argue on the basis of very general physical principles that this process will be reversed in hot interacting helium, where some of the C^{12*} will transform by emitting gamma radiation to the ground state of C^{12}, which is stable. There had been previous evidence from the work of Holloway and Moore (*46*) for the existence of a state roughly in this energy region, but Hoyle did not know this, and he indeed deduced its existence and almost exactly its energy from astrophysical evidence. In our present stage of knowledge, this is more than we are able to do from first principles.

Thus we now have a reasonable experimental basis for the two-stage process by which three alpha

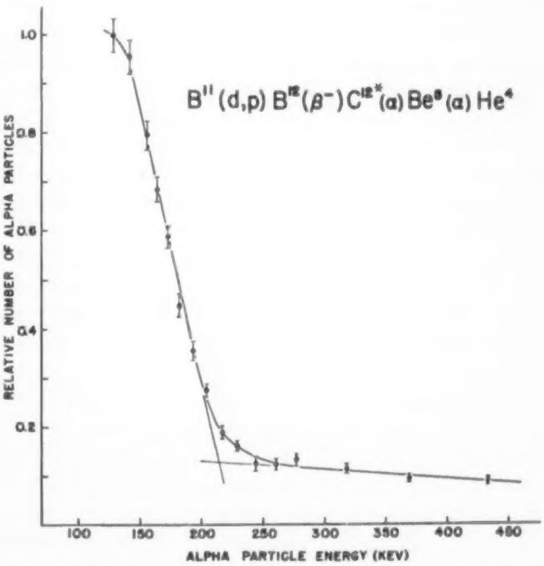

Fig. 6. Distribution in energy of the low-energy alpha particles (helium-4 nuclei) resulting from the disintegration of the excited state of carbon-12 produced by the apparatus shown in Fig. 5. Very general physical arguments lead one to expect the reverse process—namely, formation of carbon through this state—in red giant stars where alpha particles have thermal kinetic energies of the order of 100 to 200 thousand electron volts. The nuclear shorthand is to be read: A target of boron-11, B^{11}, bombarded by deuterons, d, yields protons, p, and results in the formation of boron-12, B^{12}. The B^{12} is radioactive and emits negative beta rays or electrons, β^-, and neutrinos, ν, to an excited state of carbon-12, C^{12*}. This excited state emits one alpha particle, α or He^4, leaving beryllium-7, Be^8, which breaks up into two alpha-particles.

particles in the hot dense cores of red giant stars can synthesize carbon. We are thus in a position to write down our two basic synthesis processes schematically as follows:

$$4H^1 \rightarrow He^4 \qquad (1)$$

$$3He^4 \rightarrow Be^8 + He^4 \rightarrow C^{12} \qquad (2)$$

where reaction 1 occurs in the main sequence stage of a star's evolution, and reaction 2 occurs in the red giant stage. In stars there is no difficulty at mass 5, and the difficulty at mass 8 has been surmounted. Stars that become unstable at this point will mix unburnt hydrogen and helium and the synthesized carbon into interstellar matter.

It is perhaps worth noting at this point that the possible role played by the $3He^4 \rightarrow C^{12}$ process in primeval synthesis has not been completely investigated to date. Another promising process in this regard is $2He^4 + n^1 \rightarrow Be^9$. However, it can be stated that neither of these reactions occurs to any significant extent at the low matter density (10^{-7} gram/cm^3) considered by Gamow and by Alpher and Herman as favorable for the primeval synthesis of heavy elements by neutron capture.

Considerable revision of our ideas of the early stages of an expanding universe will be necessary if any progress is to be made along these lines. If one assumes that matter predominated over radiation and had a primeval density comparable to or greater than that in stars, then light-element synthesis up to Ne^{20} by helium burning could well have occurred in the primeval stage of the universe. Whether subsequent processes would have built the heavy elements is an interesting nuclear problem, while the assumption of a primeval "matter" universe raises interesting astrophysical and cosmological questions.

Returning to the stellar synthesis, we note that the chain of element building jumps from helium to carbon and omits the elements lithium, beryllium, and boron, which are thus not produced in the main line of element production. Their rarity in nature, as emphasized previously, is in keeping with this, and we need only invoke relatively infrequent secondary processes to produce these rare elements. These infrequent processes will not occur in hot stellar interiors, for laboratory results indicate that these elements are broken up into helium by interactions with hot hydrogen rather than being synthesized. Heavy elements interacting with hydrogen do produce lithium, beryllium, and boron in a form of spallation, and such interactions in "spots" on stellar surfaces or in interstellar matter may be the source of these elements. The spots mentioned may be similar to the sunspots observed on our sun. Deuterium is destroyed in stellar interiors, but it may also be produced in stellar surfaces by neutrons escaping from hot spots and being captured by protons in quiescent regions. It may also be produced in the supernova explosions to be discussed later.

The production of C^{12} in the helium core of a star that remains stable is followed by a succession of alpha-particle captures resulting in the formation of O^{16}, Ne^{20}, and perhaps Mg^{24}. The captures probably terminate at Ne^{20} because of the exhaustion of the helium. The exhaustion of the helium will be followed by further condensation and temperature rise for the cores of those stars that remain stable. At sufficiently high temperatures, reactions among the carbon, oxygen, and neon nuclei will take place, leading to the synthesis of the silicon group of elements. As a final stage, equilibrium will be established at about 5 billion degrees, and the result will be the formation of the most stable nuclei—namely, iron and the nearby elements. It is in this connection that equilibrium theory plays an important role in the synthesis of the elements in stars. With the production of the iron group of nuclei, no further release of energy is possible from nuclear processes.

Hoyle (*15*) has suggested that the marked peak in the universal abundance curve at the iron group is due to those stars that remained stable until all nuclear energy release had terminated in the core and then subsequently in supernovaelike explosions mixed the iron group into the interstellar gas. The explosion might be induced by a sudden mixing of the hot core material with the unburnt material of the envelope. Stars may even develop shells or layers of successively heavier nuclei, unburnt hydrogen on the outside, next helium, then the carbon group, the silicon group, and finally the iron group in the core. Any instability may well lead to the ejection of some or all of this material into space. Hoyle's suggestion of equilibrium production of the iron group gives an almost exact quantitative description of the relative abundances of the isotopes of titanium, chromium, vanadium, iron, and nickel. Hoyle, Fowler, Burbidge, and Burbidge (*47*) have shown this by taking into account the known properties of the ground and low-lying excited states of the stable and beta-active nuclei involved in the equilibrium.

Let us now consider a second-generation star that has condensed from primordial hydrogen into which some C^{12}, O^{16}, and Ne^{20} and even a small amount of the iron group has been mixed by the explosions of first generation stars. In these stars, hydrogen in the core will again be processed into helium but now by a new mechanism, the one independently suggested by Bethe and von Weizsächer

in 1938. This mechanism starts with the C^{12} and is called the carbon-nitrogen cycle. In this cycle, the C^{12} interacts with hydrogen to synthesize C^{13}, the heavy isotope of carbon, and the two isotopes of nitrogen, N^{14} and N^{15}, in three successive proton captures. A fourth proton capture by the N^{15} results in alpha-particle emission and the reproduction of the original C^{12}, as shown in laboratory experiments. The result is the production of all the isotopes of carbon and nitrogen, which then serve as catalysts in the over-all synthesis of hydrogen into helium. The carbon and nitrogen isotopes change hydrogen to helium but are not themselves consumed in the process.

The survival of carbon and nitrogen in hydrogen burning in stars is obviously of critical importance in mankind's development, as well as in nucleogenesis. It is now believed that the carbon-nitrogen cycle rather than the direct proton interaction chain is the source of energy in second-generation, main-sequence stars that are large enough to have internal temperatures more than 15 million degrees. The carbon-nitrogen cycle reactions have been extensively studied by R. N. Hall, E. J. Woodbury, and A. W. Schardt at low energy in our laboratory (*48*) and at higher energies by other laboratory groups, and considerable but by no means complete evidence has been found about the rates at which these reactions occur under stellar circumstances.

Laboratory experiments indicate that O^{16} reacts with hydrogen to produce O^{17}, which then reacts to produce the carbon and nitrogen isotopes. However, Ne^{20} takes part in a second catalytic cycle involving Ne^{21}, Ne^{22} and Na^{23}. The nuclei C^{13}, O^{17}, and Ne^{21} become very important when the second-generation star exhausts its hydrogen and goes into its red giant stage, and these nuclei eventually find themselves in a hot helium core. This importance arises from the fact emphasized independently by Greenstein (*18*) and Cameron (*17*) that C^{13} interacts with helium to produce neutrons with a positive release of energy. The Burbidges (*49*) and I have pointed out that this was also the case for O^{17} and Ne^{21}. Thus a steady supply of neutrons becomes available in the red-giant stage of second-generation stars. These neutrons are readily captured by the other nuclei and particularly by those in the iron group, and heavy-element formation up to lead and bismuth occurs. Natural alpha decay of the still heavier nuclei stops the synthesis at this point.

The production of neutrons in stars makes it possible to synthesize the highly charged heavy elements at reasonable temperatures in stars because neutrons are not charged and are thus not electrically repelled by nuclei, light or heavy. The theory of the synthesis of elements in stars borrows from Gamow the mechanism of production which is so strongly indicated by the inverse correlation of abundances and neutron-capture cross sections. However, there is one very important point of difference. In primeval synthesis, the failure of He^4 to capture neutrons stopped synthesis beyond this nucleus. In stellar synthesis, the neutrons are formed in a medium consisting primarily of the one nucleus that does not capture them. They are thus available to be captured by other nuclei to build still heavier ones.

The most spectacular evidence for the production of heavy nuclei in stars has been the discovery by Paul W. Merrill (*50*) of Mount Wilson and Palomar Observatories of the existence of spectral lines of the element technetium, Tc, in the light from a certain class of giant stars called S-stars. Now technetium has not been found to occur naturally in terrestrial materials, and its longest-lived artificially produced isotope, Tc^{99}, has a half-life of 216,000 years. Since the stars in which it is observed are presumably much older than this, the technetium must have been produced during the relatively recent giant stage of the star in the star's interior and somehow or other circulated to the surface where, along with other elements, it is observed. Technetium is being continuously produced in such stars, but any that existed in the earth's original material has long since decayed away. Less spectacular but no less convincing is the fact that some giant stars show anomalous over-abundances of certain stable, heavy elements relative to the universal cosmic abundance. Element formation is taking place in stars even now.

The long-lived parents of the naturally radioactive materials, uranium and thorium, cannot have been produced by steady neutron-capture processes in slowly evolving stars. They can only be produced in rapid neutron captures involving the explosive stages of stellar evolution. Rapid captures will bridge over the alpha-particle activity that circumvents synthesis by capture at a slow rate. Evidence for rapid neutron synthesis became available terrestrially in the Bikini tests of November 1952, when it was found in the thermonuclear debris that an isotope of californium, Cf^{254}, was produced by rapid neutron irradiation of uranium (*51*). Sixteen neutrons were captured by U^{238} to form the nucleus, which rapidly decayed to Cf^{254} by emitting several electrons. Cf^{254} has the unique property that it decays spontaneously by the very energetic fission process with a half-life of 55 days.

It has been pointed out recently by the Burbidges, Hoyle, R. F. Christy and me (*52*) that this is just the half-life (55 ± 1 nights) observed in the decreas-

ing light intensity of certain supernovae after their original flare-up observed by F. Zwicky, W. Baade (*53*) and R. Minkowski (*54*) of Mount Wilson and Palomar Observatories. Regardless of the extreme provincialism implied, we think that californium-254 is produced in supernova explosions and that its especially energetic decay with a conveniently observable lifetime makes its presence stand out, but presumably other heavy elements are produced in a similar manner. (We have made an honest but fruitless search for similar unique properties among the isotopes of elements called by any other name than californium.) This highly unclassified result came to light within less than 4 weeks after the publication of the Bikini test results after a lapse of almost 4 years.

Thus there is evidence for both rapid and steady neutron synthesis of the heavy elements in the astrophysical observations of the production of radioactive californium and technetium. An important consequence of these two modes of neutron synthesis is that all neutron-rich isotopes can be produced; there are no "shielded" abundant nuclei left out of the two mechanisms of synthesis. The fission of the transuranium elements also leads to production of some of the stable heavy elements. Finally, we need to call only upon infrequent equilibrium processes at very high temperatures to produce the very rare proton-rich isotopes. There is good evidence in the abundances of these rare isotopes that they are genetically related and that they were all formed in hot hydrogen surroundings or in regions of intense gamma radiation.

The general processes involved in the synthesis of

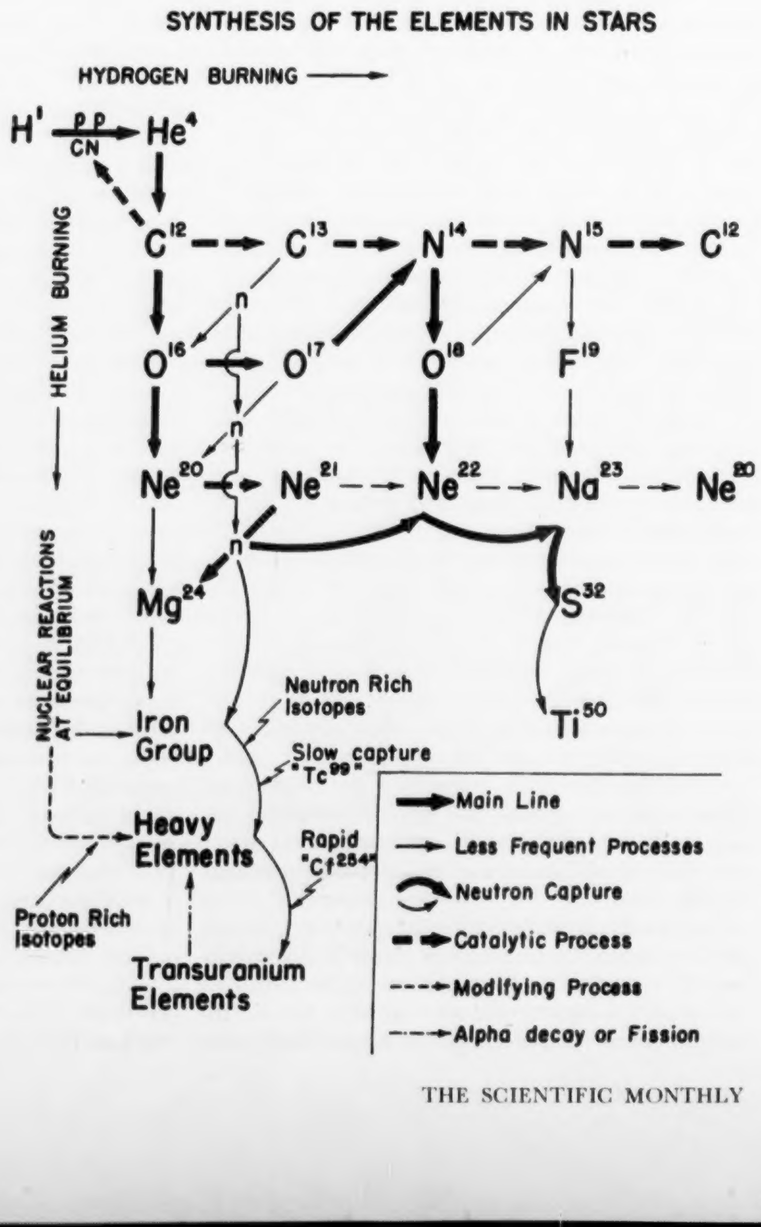

Fig. 7. A schematic diagram of the nuclear processes by which the synthesis of the elements in stars takes place. Elements synthesized by interactions with protons (hydrogen burning) are listed horizontally. Elements synthesized by interactions with alpha-particles (helium burning) and by still more complicated processes are listed vertically. The details of the production of all of the known stable isotopes of carbon, nitrogen, oxygen, fluorine, neon, and sodium are shown completely. Neutron capture processes by which the highly charged heavy elements are synthesized are indicated by curved arrows. The production of radioactive Tc^{99} is indicated as an example for which there is astrophysical evidence of neutron captures at a slow rate over long periods of time in red giant stars. Similarly Cf^{254}, produced in supernovae, is an example of neutron synthesis at a rapid rate. The iron group is produced by a variety of nuclear reactions at equilibrium in the last stable stage of a star's evolution.

the elements in stars are illustrated in Fig. 7. It must be emphasized that this diagram is schematic and somewhat tentative. It is the first draft of an index to a still unwritten book on nuclear cookery. Qualitatively, we see reactions by which all of the elements can be synthesized in stellar processes, but there is a great amount of detailed quantitative research to be done before this point of view can be established as scientific fact. There is always the disconcerting realization that no single process seems to have synthesized all of the elements. If we are on the right track, considerable simplification in element-building processes in stars is almost certain to occur as our understanding becomes more complete. On the other hand, to the experimentalist an attractive feature of this point of view is that it leads to a program of cooperative research in the nuclear laboratory and in the astronomical observatory. Nuclear reactions can be studied by the nuclear physicist, and their effects in stars can be observed by the astrophysicist. Nuclear spectroscopy may become as useful to the astrophysicist as atomic spectroscopy. It is worth noting that cosmological speculation can now be checked by two independent experimental methods, nuclear and astrophysical.

Conclusion

I conclude with two final sets of remarks. First we note that the sun and the earth and the solar system contain practically as many of the heavy elements as any system astronomers have studied. The production of these elements took time—an estimate of at least 2 billion years of stellar evolution and periodic supernova explosions in our galaxy before the formation of the solar system is reasonable. The present ratio of the two isotopes of uranium, $U^{235}/U^{238} = 1/140$, is consistent with general arguments pointing to their formation (*47*) in equal amounts (*55*) and with their known relative decay rates only if their synthesis took place at least 6 or 7 billion years ago. If the synthesis occurred uniformly over an interval of time, this interval preceding the formation of the solar system must be of the order of 3 billion years or even greater. This is all consistent with meteoritic determinations of the age of the solar system as 4.5 billion years and with the globular cluster determinations of the age of the oldest system in our galaxy as 6.5 billion years. Thus many cosmic events preceded the formation of our earth with its rich heritage of the products of such events.

Since Copernicus we have not believed our earth to be central in the solar system; in recent times, we have found that our sun is not central in the galaxy. If we accept the point of view of the synthesis of the elements in stars, then we see that the sun and the earth are not central in time—that is, that they did not originate at the beginning of our galaxy. The philosophic and religious consequences of this removal of the last vestige of our intuitive geocentric concepts can be readily imagined.

As the second of these concluding remarks, I wish to comment on astrophysical time scales and their measurement by nuclear means. Nuclear physics has not provided us with a continuously running clock because, after all, radioactive sources do run down. It has, however, provided a series of hourglasses, as it were, of widely differing periods from which we have been able to choose appropriately in attempting to establish particular periods or intervals of time of interest. There is first of all C^{14} with a half-life of approximately 6000 years which has been very useful in elucidating dates and periods on the time scale of recorded human history. U^{235} with a half-life of about 1 billion years and U^{238} with a half-life of 5 billion years have been used in combination to measure the age of the oldest rocks and even of the meteorites and of the earth itself. The age of the earth and presumably of the solar system is almost exactly equal to the half-life of U^{238}. In our discussion, we have noted that the interval for element synthesis before the formation of the solar system must be of the order of the half-life of U^{238} and could even be greater. An important hourglass still available to us is Th^{232} with a half-life of 14 billion years. It will be interesting to see as our studies proceed if there is some timelike aspect of our galaxy or of our universe which will be appropriately measured by this 14-billion-year hourglass (*56*).

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56. This work was supported in part by the joint program of the Office of Naval Research and the U.S. Atomic Energy Commission.

BOOK REVIEWS

The Search Beneath the Sea. The story of the coelacanth. J. L. B. Smith. Holt, New York, 1956. 260 pp. Illus. $3.95.

Most readers will be familiar with at least the outlines of the story of the discovery of the remarkable "living fossil," the coelacanth *Latimeria.* This book is the personal—very personal—story of its discoverer, J. L. B. Smith, South African ichthyologist, and of the vexations and tribulations he encountered in tracing the animal to its native habitat.

The coelacanths are a marine offshoot of the Crossopterygii, a group essentially ancestral to land vertebrates and, hence, of evolutionary importance. Typical crossopterygians have been extinct since the Paleozoic; the fossil record of the coelacanths extends to the Cretaceous, some 70 million years ago, and then stops. In consequence, I (like many another lecturer) used to tell my class, emphatically, that "there are no living crossopterygians." And I can well remember my amazement, in the winter of 1939, at seeing in the *London Illustrated News* a photograph of a living—or rather recently living—coelacanth!

In East London, South Africa, there is a Miss Latimer in charge of a local museum. One day, as she looked over the oddments of a trawler's catch, there appeared a large, 5-foot fish of a sort unknown to her or to the trawler's crew and, hence, worthy of preservation for the museum. She sent a sketch of the fish to Smith, in nearby Grahamstown. Unluckily, he was away from home, and it was some time before he received the letter, recognized the almost unbelievable nature of the find, and could return to study the specimen. Unfortunately, it had not been possible to save the specimen except by stuffing and mounting it, which meant that nothing was left of the animal except the skin and part of the skull. But surely this animal was not the last of its tribe, and although it was unquestionably a stray in the East London region, search should locate the coelacanth home—presumably somewhere in the Indian Ocean up the East African coast.

War intervened, and it was six years before the search could be taken up. Grandiose schemes for a coelacanth hunt were drawn up by the South African government and others. All fell flat, and Smith undertook the quest alone. Work in ichthyology took him up and down much of East Africa. Everywhere he inquired for traces of the coelacanth, and handbills, with a picture of the fish and offer of a reward, were spread far and wide. But it was not until 14 long years after the first discovery that a second specimen was found and the home of the coelacanths was discovered. Just before Christmas of 1952, Smith received a cable from a schooner captain that a specimen had been taken near the shores of the Comoro Islands, a French territory off the north end of Madagascar.

How to rescue this valuable specimen from this isolated region to which public transportation did not extend? It was the Christmas holidays, and friends and officials who might have aided were scattered from their posts. Finally a direct appeal to Premier Malan of South Africa won success. A plane was provided, and with a Navy crew Smith flew to the Comoros and returned triumphantly with coelacanth number 2.

At this point, however, his contact with coelacanths ended. It is often said that science is international. It is in spirit; but in actual practice, nationalism may interfere with science, in ichthyology as well as atomic physics. The French government decreed that foreign workers should be excluded from the islands. In the past few years more than half a dozen splendid coelacanths have been caught there. They are now in the capable hands of Millot and his associates in the laboratory of comparative anatomy at the Jardin des Plantes, and the first of a series of monographs on the anatomy of *Latimeria* has already appeared. But it must not be forgotten that (as Millot himself clearly and generously acknowledges) it was Smith's efforts which led to the discovery of the home of the coelacanths and made possible the work of his French colleagues.

A. S. Romer

Harvard University

Greek Science in Antiquity. Marshall Clagett. Abelard-Schuman, New York, 1955. xii + 217 pp. Illus. + plates. $4.75.

The 20th century of the Christian Era is the first to which the study of Greek science in antiquity will appear largely an antiquarian pursuit. Little more than a generation ago scientists received part of their mathematical training directly from the works of one of the Greek scientists of antiquity, Euclid. One need not go back to the Dark Ages to find the works of Galen, Archimedes, and others on the shelves of the practicing scientist. In short,

the emancipation of science from dependence on "Greek science in antiquity" is a distinctly modern development.

Consideration of this suggests that a science which enjoyed such prestige for more than 2000 years represents a phenomenon worthy of our notice. The recent reemergence of a feeling for the unity of science, after a century of relative isolation of the several sciences, also raises questions upon which the study of Greek science may cast light, for it represents a tangible example of science in being and action over a period of nearly 1000 years.

Since the disappearance of its last residue from our system of science education, Greek science seems to have become the property of historians. General works and textbooks have not usually been such as to appeal to the scientist. The steady, if gradual, increase of interest in the history of science in this country is reflected in the appearance of this book, which goes far to meet the need both as a textbook and as a general work.

Marshall Clagett's comprehensive knowledge of the early Christian Era is reflected in the allocation of the latter half of the book to this period, which is indeed the phase of Greek science that is most likely to prove instructive to those interested in the character and development of science. The "golden age," from Aristotle through the beginning of the Christian Era, is treated more briefly than usual here, justifiably it seems to me, for no introduction can delve adequately into the richness of this period, nor is the attempt necessary since the reader can easily refer to the *Source Book in Greek Science* of Cohen and Drabkin and the editions in the Loeb Classical Library to which Clagett refers the reader.

Clagett's well and judiciously written book deserves an enthusiastic reception from the community of scientists.

ROBERT P. MULTHAUF
Smithsonian Institution

Opinions and Personality. M. Brewster Smith, Jerome S. Bruner, and Robert W. White. Wiley, New York; Chapman & Hall, London, 1956. 264 pp. $6.

Walter Lippman has recently argued that in modern democracy the public exerts a kind of tyranny over those who fill positions of power. The particular nature of this tyranny is that, in their political sensitivity to "public opinion," our leaders are not free to execute those policies and strategies which, although suggested by their "higher knowledge and experience," would arouse public disapproval. The assumption upon which such an analysis rests is, of course, that public opinion is frequently uninformed, undifferentiated, and irrational.

In an age that demands intelligent and informed opinion at all levels if great decisions are to extricate us from great dilemmas, the study of public opinion becomes something of a societal, as well as a scientific, imperative.

It is a particular value of this new book by three Harvard psychologists that in reporting an interesting investigation of the relations between opinion and personality variables, it helps to illuminate some of the processes by which informed and uninformed, thoughtful and thoughtless opinions arise and are maintained.

The research project which this book reports was conducted during the years 1946 and 1947 by a group of clinical and social psychologists (and one social anthropologist) at the Harvard University Psychological Clinic.

To each of the ten subjects there was administered an exhaustive, and probably exhausting, battery of personality-assessment tests and interviews. In turn the subjects were painstakingly investigated with regard to their attitudes toward the Soviet Union. The two bodies of data thus collected were analyzed and related to each other through the medium of depth-psychological interpretation. The yield, in terms of advancing our understanding of opinion, both as an expression of personality and as adaptive behavior in the service of personality maintenance, is considerable.

Although they have not directly concerned themselves, as has Lippman, with the question of the worth (in terms of its "objectivity") of public opinion, these researchers have nonetheless convincingly demonstrated the correctness of their basic proposition: that the individual's opinions on public (or for that matter, private) issues are shaped through the interaction of personality and "information" and that the end-products of this interaction serve the general requirements of ego-defense and motive-reduction.

To be sure, the authors have been constant in their vigilance against the argument *ad hominem*. In their own words, "the soundness or truth of an opinion must be judged by criteria other than its adaptive service to the person who holds it, and its adaptive service should by no means be conceived as simply a source of error."

However, their research does make clear (at least with relation to the development of opinions about the Soviet Union) that certain patterns of personality-based need, conflict and expressive

style dispose the person to seeking detailed information and to constructing complex, differentiated cognitive structures. One might go on to assert (as the authors *do not*) that such findings are at least suggestive that on given topics, and other things being equal, the opinions of some kinds of people are worth more than the opinions of other kinds of people.

From the point of view of the social psychological specialist, this book offers a good deal that should arouse interest and, possibly, argument. Especially noteworthy in this regard is the authors' division of the adjustive function of opinion into the three categories of "object appraisal," "social adjustment," and "externalization." Also of considerable interest to the psychologist is the demonstration afforded by this study of how the intensive case-study approach may be creatively used to investigate problems beyond the realm of conventional clinical research.

A major question that will occur to many psychologists who read this interesting account of a valuable investigation is just how the insights and leads that these researchers have garnered may best be systematically formulated and experimentally tested.

MILTON J. ROSENBERG

Yale University

The Wheat Industry in Australia. A. R. Callaghan and A. J. Millington. Angus and Robertson, Sydney and London, 1956. 486 pp. Illus. 63 s.

Wheat growing in Australia made a stumbling start at the end of the 18th century, when the first crop was grown by released convicts on laboriously hand-hoed ground. Today the Australian wheat-growing industry has reached such a size that it claims for Australia a place among the "Big Four" wheat-exporting countries of the world (United States, Canada, and Argentina).

This book gives a full and expert description of the development and present status of the Australian wheat-growing industry, from a technical, as well as a historical, point of view. Of special interest to the American reader is the account of the development of the harvesting equipment which has served as the prototype for the gigantic combines now used all over the world.

There are many excellent illustrations and a full list of references.

JOHN HANCOCK

International Bank for Reconstruction and Development

Between the Planets. Fletcher G. Watson. Harvard University Press, Cambridge, Mass. rev. ed., 1956. 188 pp. Illus. + Plates. $5.

The Harvard Books on Astronomy, of which Fletcher Watson's book is a member, form an excellent series, which presents in popular, yet authoritative, form almost the entire field of astronomy. This edition of *Between the Planets* capably presents the smaller bodies of the solar system and leaves the reader with an honest impression of how much is known, and how much more remains to be learned, about these important objects.

An extra chapter in the new edition on the radio observations of meteors underscores again the tremendous impact of radar and radio techniques on astronomy since the first edition was published in 1941. This much can be seen by merely comparing the tables of contents. But a reading of the text brings out many other developments that have taken place in the intervening 15 years.

In addition to the planets, the material of the solar system may be divided into four main categories: asteroids, comets, meteors, and interplanetary dust. It is in the second and third of these that progress has been most marked. Whipple's model of a comet nucleus, consisting of ices of water, ammonia, methane, and other substances, has done much to bring into a consistent picture the numerous observations of comets and, at the same time, has had an important bearing on the nature of the meteors. The work of Whipple and his associates at Harvard on meteors, and on the upper atmosphere as it is revealed by meteor studies, is well known.

Meteors have been the subject of extensive investigation on a number of fronts in recent years. Radio studies are perhaps the most spectacular. Although radio signals associated with meteors were recognized as early as the Leonid shower in 1931, and meteor "whistles" were discovered in 1941, the wartime development of radar provided the most powerful tools in this direction. Under Lovell and Clegg and their associates at the Jodrell Bank station of the University of Manchester in England, radar meteor studies have been prosecuted vigorously since 1947. Their discovery of daytime meteor showers, observable only by these means, is highly exciting, but numerous other data have been found as well.

Laboratory study of meteorites provides the only case in which cosmic matter can be analyzed with all the techniques of chemistry, metallurgy, and modern physics. As these fields have been rapidly developing, so has their influence on the under-

standing of meteors. The work of Harrison Brown and his coworkers is particularly important. New progress on the determination of ages of meteorites from radioactivity disintegration products, in which Paneth has figured prominently, is important in its bearing on the origin and history of these objects.

It has become increasingly clear in recent years that dust (and gas) in space is at least as significant as the stars themselves for an understanding of the development and operation of a system of stars such as the galaxy. Birth of new stars, and presumably of solar systems, appears to be intimately related to, and dependent on, the nature of clouds of the smaller dark bodies. Study of these bodies in our own solar system as comets, meteors, or dust, combined with the asteroids which seem to be the remains of a shattered larger body, shed light on the origin of the solar system and the planets and also on the nature of the material elsewhere in the galaxy which we cannot reach with even the same degree of convenience. Many facets of these studies not mentioned here are covered in Watson's book, which should serve to stimulate still more interest in this field of current endeavor.

ROBERT FLEISCHER

Rensselaer Polytechnic Institute and Dudley Observatory

Proceedings of the Third Berkeley Symposium on Mathematical Statistics and Probability. Held at the Statistical Laboratory, University of California, December 1954; July and August 1955. Vol. IV, *Contributions to Biology and Problems of Health.* Jerzy Neyman, Ed. University of California Press, Berkeley, 1956. 179 pp. Illus. $5.75.

This is one of five separate volumes containing proceedings of the third Berkeley Symposium on Mathematical Statistics and Probability held in December 1954 and July–August 1955 at the University of California, Berkeley. The present volume is concerned with problems in the field of biology and public health.

Two papers related to some genetic problems and one on a study in population ecology constitute the section on biology. The six contributions to problems of health include papers in epidemiology, studies in medical diagnoses, problems arising from retrospective studies, and problems of contagion.

The relatively newer concept of a stochastic model (one allowing for chance or random variation—in fact, making this an integral component of the system) for the study of biological phenomena is emphasized without discarding or minimizing the importance of the deterministic models that enjoy a prominent place in the historical development of many of the problems discussed. In several of the papers, the two approaches are used to complement one another, the deterministic scheme frequently providing a convenient approximation and furnishing the impetus for probing more deeply into the underlying mechanism of the process.

The volume should prove rewarding to those who are interested in the theoretical aspects of these problems and who are equipped with the background of mathematical statistics needed to take advantage of the several new methods of attack suggested in these papers. However, the following features of the collection suggest that it is a valuable addition to the library of all research workers in these fields.

1) Many of the papers are the result of collaboration between experimentalists and theoreticians, the problem under discussion being presented in its natural setting and the stages in the development of the consequent mathematical model being clearly motivated. The contributors evidence a very real effort to tie in theory with applications and to emphasize their purpose of attempting to find an explanation of the underlying biological processes.

2) Historical surveys or summaries of previous work and of other current work in progress, provided at the outset in most of the papers, together with unusually full bibliographies at the end of each paper, constitute a valuable service to the individual working in any aspect of the problems discussed.

3) Many problems and suggestions for further research and experimentation are given. The authors are frank in admitting the limitations and inadequacies of some of the theories and practices at their present stage and indicate work yet to be done.

GRACE E. BATES

Mount Holyoke College

Toward a Unified Theory of Human Behavior. Roy R. Grinker and Helen MacGill Hughes, Eds. Basic Books, New York, 1956. 375 pp. Illus. $6.50.

This volume is not just another multiple-authored treatise in the social sciences such as have appeared with increasing frequency in recent years. Rather, it is an important attempt by a group of biological and social scientists to review the struc-

ture and theories of their respective disciplines and identify those transcendent conceptions which may be invoked to provide a unified theory of human behavior. This endeavor was aided by a grant from the Carnegie Foundation to the Institute for Psychosomatic and Psychiatric Research and Training of the Michael Reese Hospital. Roy R. Grinker served as chairman of the several conferences whose proceedings constitute the substance of this volume.

The participants, whose avowed purpose was to achieve a "more unitary approach to man . . . a first approximation to a scheme which will enable us to represent physical, psychological, and social events within one system of denotation," comprise a distinguished body of scholars ranging over the "life science" disciplines from anatomy and biology, through psychology and psychiatry, to sociology, anthropology, and government.

The proceedings of the first four conferences only are presented in this volume. The first of these consists of some general theoretical orientations to the behavioral sciences presented in the form of essays to which have been appended pertinent comments and discussion contributed by members of the conference. Here we find, among others, a succinct statement of Talcott Parson's theoretical approach, a discussion of a universal system of value orientations by Florence Kluckhohn, a modified psychoanalytic schema by David Shakow, and the statement of a system of socio-psychiatric invariants by Jules Henry.

The second and third conferences were devoted to comparisons of systems of thought and in particular to an examination of the concepts of homeostasis, communication, and the nature of transactional relationships. Included also is an extensive consideration of the problems of observation in the behavioral sciences and the theoretical nature of boundaries. Chapter 21, concluding the third conference, presents a general summarizing discussion, together with an outline of a "system of relationships relevant in a unified theory of behavior," which, to me, provides a nice condensation of the thought advanced in the preceding chapters. The final conference is devoted to a discussion of the meaning and conceptualization of boundaries, including an interesting discussion of mathematical interpretations of this concept by Anatol Rapoport.

This is not a book which a person unfamiliar with the behavioral sciences is likely to find rewarding. At times it is difficult, obscure, and abstract. It is also a running report of theoretical speculation in the making, not a statement of a final, consistent system. Toward such a system, however, it undoubtedly makes progress. The convergence of these scholars upon the concepts of homeostasis, transactional relations, and communication of information surely marks a forward advance in the integration of thought in the behavioral sciences.

Robert H. Knapp
Wesleyan University

Handbook of Biological Data. William S. Spector, Ed. Prepared under the direction of the Committee on the Handbook of Biological Data. Saunders, Philadelphia, 1956. 584 pp. $7.50.

The *Handbook of Biological Data*, in preparation by a National Academy of Sciences–National Research Council committee for the past 7 years, was published in October 1956. More than 17,000 biologists contributed to the preparation of the first *Handbook of Biological Data*. The need for such a handbook, including selected, authoritative, standard values and estimates of variability for such values, is obvious to every biologist who needs information outside the immediate field within which he may himself be an expert. The teacher, the student, and the industrial user of biological materials have equal need with the research worker. The handbook was prepared for all these biologists, and it will be useful to them.

The Handbook Committee has served effectively as an advisory and review board. Its basic task was the definition of scope and of audience to whom the handbook is addressed. It was their decision that the handbook should be abridged and that it should be addressed primarily to persons with frequent need of information outside their own area of specialization. Every member has contributed to definition of the parameters within which the first edition has been abridged. They have aided in selection of topics, in evaluation of proposed tables, and in the weighting of areas to be covered. They have reviewed procedures for selection and authentication of data.

This first edition of the handbook contains some tables in each of the major areas of biology. Space devoted to particular areas must reflect in some measure the availability of important, quantitative data within that area. Later editions will include additional tables, as users define deficient areas and adequate data become available.

Diagrams, concise summary statements, and structural formulas have been used when appropriate, although tabular data constitute the major portion of the handbook. The diagrams indicating pathways of metabolism, the theories of blood coagulation, and others, provide elegant, simple pres-

entations of complex basic theory. Words, not numbers, were needed to construct tables concisely stating and relating structure and function. Qualitative data, or those crudely but not numerically quantitative, have been expressed in words, or, in a few cases, by the traditional pluses and minuses. In fact, no appropriate means of printed communication required to present essential information has been overlooked.

T. C. Byerly

Agricultural Research Service,
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Introduction to Microfossils. Daniel J. Jones. Harper, New York, 1956. xviii + 406 pp. Illus. $6.50.

More than 100 years ago d' Orbigny (1802–57) was publishing on microfossils; by this I mean not only his microcephalopods (Foraminifera) but all sorts of microscopic fragments that were present in his samples. Then various others doing similar work separated off on Foraminifera, ostracods, spores, pollen, and so forth, and became more specialized, and there grew up a literature on microfossils, but for some unknown reason no one apparently felt the urge or need for a single volume to bring the field together in a textbook. At first thought this idea of a textbook sounds impossible, for it must cover such a wide biological field; but, as anyone who has examined sediments for microfossils realizes, plants and animals live together and are fossilized together. Also small fragments of macrofossils and their microstructure can be identified. Hence, it is natural that the student of microfossils will probably see a great variety of objects and should be able to recognize them. Daniel Jones has brought together his experiences as a research geologist and a teacher of micropaleontology in this book, which cuts across biological districts.

After a short historical introduction, field sampling and collecting are discussed, with the important caution to clean all tools between each collection and prevent contamination of a sample by other micromaterial—for example, recent pollen in fossil material. After one has the sample, it must be treated by crushing, soaking, boiling, either in tap water or with chemicals, freezing, digestion in acids, and so on, to free the microfossils. Next the microfossils must be picked out and mounted for study.

Chapter III is a synoptic classification of organisms, with reference to microfossils—the kingdom Protista, the kingdom Plantae, the kingdom Animalia, and "doubtful affinities." The microfossils of Protista, plant microfossils, animal microfossils with conodonts, ostracods, and Foraminifera, are dealt with in considerable detail in separate chapters. Chapter X, "Environmental significance of microfossils" discusses microfossils in nonmarine environments, mixed environments, and marine environments. The mixing and displacing of microfossils are more easily possible than for the larger fossils, and this subject is treated in some detail.

In Chapter XI Jones takes up, period by period, the occurrence of microfossils of some dozen phyla and, for the Protista, lists genera. The last chapter, which is entitled "Applied micropaleontology," discusses primarily petroleum exploration and paleofacies. Then follow appendixes on the use and care of the microscope, classification and nomenclature of organisms, illustration of microfossils, and a glossary of generic and specific names in common use. This is not a catalog but a sort of dictionary that should prove quite useful. The book is completed with a general glossary, a general index, and an index of fossils.

It should be a very useful book, especially since it fills a void that has existed for many years. Jones has done an excellent piece of work in reviewing such a broad field. His references are, in general, well selected, but they are not cross-indexed; that is, they are located after each chapter or parts of a chapter and are referred back to as "See under subject," in whichever chapter it is. I find this laborious in checking references, and if they are worth printing it should be easier to use them. Eleven of the figures have to be read by turning the book, which is a nuisance. In spite of these mechanical difficulties, the book is a valuable contribution and, it seems to me, should find wide use both as a teaching book and a reference book for industrial use.

E. Willard Berry

Duke University

Fun with Figures. J. A. H. Hunter. Oxford University Press, Toronto, 1956. 160 pp. $3.

This is a presentation of the lighter side of mathematics—a series of mathematical puzzles designed to prove that "mathematics can be fun." The volume consists of a series of 150 mathematical problems made up in the form of amusing anecdotes. Fifteen typical solutions are included, and each problem is keyed to the typical solution in a list which will enable the reader to get a start if such is needed. A complete set of answers is in-

cluded for use after the problem has been solved. The following are typical "problems."

A Tale of the Cats

The lucky cats in Stratton Street
Had seven mice apiece to eat.
The rest made do
With only two:
The total score
Being twenty-four.
How many cats ate mousie meat?

Her Secret

"How old are you, Gran?" asked Ken politely. The old lady smiled at the little boy. "That's a question no gentleman should ask," she replied, "but I'll tell you if you promise to keep it a secret."

Ken nodded, and his grandmother went on: "If you reverse my age you'll get half of what I shall be in a year's time."

That kept him quiet for a while, but what do you make her age?

Corn and Its Early Fathers. Henry A. Wallace and William L. Brown. Michigan State University Press, East Lansing, 1956. 134 pp. Illus. $3.75.

This book of some 134 pages contains much information of interest to the average reader as well as some history that is particularly pertinent to anyone working with corn. In fact there is such a wealth of information in this book regarding corn and the corn workers that it is a must for anyone contemplating corn research.

One of the chapters is entitled "Certain philosophic aspects." I think that these philosophic aspects are not confined to this one chapter but permeate the book. The authors start by giving something of the history of corn, pointing out that recent borings in Mexico have revealed the fact that corn pollen must have been produced in that area as early as 50,000 years ago. This may cause us to revise some of our notions regarding the history of corn. Apparently the corn plant as corn has been with us a long time. This is of no surprise to me, since I postulated the theory that corn might have arisen from a wild corn grasslike plant by a single mutation giving the typical corn plants that we know today [*American Naturalist*, 1951].

Corn and Its Early Fathers contains information regarding some little known men who contributed markedly to the corn-belt corn which is now commonly believed to have originated either from accidental or intentional crosses of eight-rowed flint corns with the Virginia gourd seed. The authors review the work of such men as Darwin, James Logan, Beal, Paul Dudley, and Cotton Mather, who conducted experiments on crossing and its effects on maize. These contributions of the early Colonial fathers and their maize experiments had been pointed out by Conway Zirkle in 1932 [*Journal of Heredity*] and by one of my own publications in 1935 [*Journal of Heredity*] concerning the importance of the work of William James Beal. Wallace and Brown also tell the story of Robert Reid and his son James Reid in developing Reid's Yellow Dent; they also give the stories of George Krug, who made remarkable selections from Reid's Yellow Dent, and about Isaac Hershey, who developed Lancaster Sure Crop in Pennsylvania. There is a chapter on P. G. Holden and his contribution to getting farmers interested in growing corn for yield test.

In addition to these more or less well known workers, Wallace and Brown have discovered some new corn men who made considerable contributions to the development of some of the corn-belt varieties. These men were John Lorain of Pennsylvania, Joseph Cooper from New Jersey, and Peter Brown who was a professor of geology and mineralogy at Lafayette College. The authors have done a real service to the history of corn in bringing to our attention the work of these early men.

Wallace and Brown have done a good job of setting the record straight on hybrid corn, giving the proper importance to the work of George Harrison Shull and Edward Murray East, whose works are often confounded and confused. The senior author is particularly well qualified to write regarding the history of hybrid corn, since he was the first of the commercial men to become interested in this phenomenon of hybrid corn.

One of the most interesting chapters in this little book is "Small gardens and big ideas," which points out that the really remarkable contributions to our knowledge about corn came from careful observations on comparatively few plants on small plots. This was true of the work of James Logan, William Beal, George Shull, and Edward Murray East, all of whom grew comparatively few plants but lived with those plants and learned a lot about them. I should like to quote one paragraph from the book.

"Corn breeding has advanced to the point at which it is no longer satisfactory to rely upon simple observation as a measure of one's progress. Marked improvements in characteristics selected for are no longer easy to obtain and as a result refined measurement is usually necessary to detect

real differences. Yet we feel that nothing can replace the value to a breeder of careful study and understanding of his plants, study of a type advocated and so successfully practiced by Dr. Beal. More and more we feel that grave danger exists of statistics being used as a substitute for critical observation and thought. Statistics have their place, a very wonderful one, but they can never serve as a substitute for close association with plants. . . . The great scientific weakness of America today is that she tends to emphasize quantity at the expense of quality; statistics instead of genuine insight, immediate utilitarian application instead of genuine thought about the fundamentals. The American approach has performed miracles in utilizing our great resources in record breaking time. We have become the best exploiters in the world but in many fields we have not always become the best researchers. Europeans did most of the basic work in atomic physics. We used our wealth, our power, our mechanical ingenuity to put to work what the Europeans had discovered . . . . We believe that true science cannot be evolved with the mass production methods. We are appealing to the spirit which caused James Logan, W. J. Beal, E. M. East and George Shull to do their work with little money, land and equipment. It was right that this work should be followed by men who had the resources to do things in a big way. These last were making roads where the trail had already been blazed. We are saying that there is still a great and glorious opportunity for *trail blazers* as well as road makers in 1956."

W. RALPH SINGLETON

University of Virginia

Aquatic Insects of California, with Keys to North American Genera and California Species. Robert L. Usinger, Ed. University of California Press, Berkeley, 1956. ix + 508 pp. Illus. $10.

Most of the chapters of this book consist of illustrated taxonomic keys prepared by experts in each of the 13 orders of aquatic insects. The book has 16 authors, including Robert Usinger, the editor. The introductory material is an illustrated treatment of both theoretical and practical aquatic entomology. The theoretical portion is concerned with aquatic communities, adaptations of aquatic insects, and stream and lake classification. The practical portion is about such diverse subjects as the relation of aquatic entomology to mosquito control, stream management, and the tying of flies for the fisherman. The introduction also contains a discussion of equipment and techniques for collecting, quantitative sampling, the study of fish stomach contents, and the like.

The editor remarks in the preface that the book is a "direct outgrowth of University of California Syllabus SS *Biology of Aquatic Insects* . . . . ," that useful set of keys and practical information to be found in the libraries of many entomologists. Yet *Aquatic Insects of California* is more than the extension of a teaching syllabus. The efficiency of the syllabus keys is vastly increased by the addition of plates illustrating life-history and taxonomy. Although the illustrations have been secured by Usinger and his associates from many sources, special mention should be made of the fine original plates of Celeste Green and Arthur Smith.

In the face of this impressive array of illustrations, I find the failure of the printer to reproduce some of the plates with the same high standards of the authors and artists all the more regrettable.

The entomologist and invertebrate zoologist will be hopeful about the value of this book outside California, since it represents a convenient compilation of old and new information. Little can be said on the point except that the book functions well in the study of the estuarine insect fauna in the New Orleans area.

JOSEPH H. YOUNG

Tulane University

In Search of Adam. The story of man's quest for the truth about his earliest ancestors. Herbert Wendt. Translated from the German by James Cleugh. Houghton Mifflin, Boston, 1956. 540 pp. Illus. + plates. $6.50.

After enjoying this skillful unraveling of the way in which a man came to recognize his own origin and his true place in the universe, it is hard to avoid a physical comparison between Herbert Wendt's story and some of the better histories of biology. From this comparison, his detective-story approach seems even bolder. Although the indexes of both include the same names, Wendt's account alone shows the sparkle of anecdote and the benefit in cleaving to a central theme.

In Search of Adam is a book about people, more than 300 of them, and the ideas they held as new scientific facts came to light. Using the technique of the historical novelist, the author has imaginatively reconstructed the thoughts and conversations of his famous characters, showed the interplay of personalities, and at the same time kept his eye on the significance of concepts and discoveries. By avoiding scientific terminology almost com-

pletely, the book can retain the interest of the general reader. For the uninitiated the great names of biology unfold in their logical sequence, in relation to the evolution of understanding.

For the scientist who reads *In Search of Adam*, the experience is something like seeing a Cinemascope extravaganza of a play read in school. The characters are familiar, but the picture takes on new life. Wendt's turn of phrase, his subheadings, his chapter titles, are all good showmanship: "Adam knocks at the back door"; "The swallow at the bottom of the sea"; "Animals too have a soul"; "The unclassifiable bastards"; "Adam disowned"; "The devil is a vegetarian"; "The flood was an ice age"; "Monkey business over Adam"; "To hell with the gorilla!" "The miracle in a monastery garden"; "Cain buried his brother Abel"; "Adam unmasked"; "Do you speak Chimpanzee?" "The baby ape in man"; "The Transvaal Garden of Eden"; "Comrade cave bear"; and so on.

Some of Wendt's statements are tantalizing, and he provides no references with which to follow them up. The indexing is odd: for example, the four pages describing the Dayton, Tennessee, trial of John Scopes for teaching evolution can be found under Dayton but not under Scopes or the two lawyers whose arguments provided the fireworks and made history; "monkey trial" is also blank.

LORUS J. and MARGERY MILNE
University of New Hampshire

Books Reviewed in SCIENCE

7 December

Atomic Quest, A. H. Compton (Oxford University Press). Reviewed by W. F. Libby.

Kernmomente, H. Kopfermann (Academische Verlagsgesellschaft). Reviewed by F. Bloch.

Automation, Department of Scientific and Industrial Research (H.M. Stationery Office). Reviewed by P. F. Drucker.

New Concepts in Flowering-Plant Taxonomy, J. Heslop-Harrison (Harvard University Press). Reviewed by R. W. Holm.

Modern Views on the Secretion of Urine, F. R. Winton, Ed. (Little, Brown). Reviewed by W. D. Lotspeich.

14 December

Numerical Analysis, vol. VI, J. H. Curtiss, Ed. (McGraw-Hill). Reviewed by J. Todd.

Body Measurements and Human Nutrition, J. Brožek, Ed. (Wayne University Press). Reviewed by W. M. Krogman.

Currents, Fields, and Particles, F. Bitter (Technology Press; Wiley; Chapman & Hall). Reviewed by W. Hornyak.

A Handbook of Hardwoods, Compiled by the Forest Products Research Laboratory, Department of Scientific and Industrial Research (H.M. Stationery Office).

Traité de Pharmacie Chimique, 5 vols., P. Le Beau and M.-M. Janot, Eds. (Masson; Stechert-Hafner). Reviewed by A. Moraczewski.

Procedure in Taxonomy, E. T. Schenk and J. H. McMasters; A. M. Keen and S. W. Muller, Eds. (Stanford University Press). Reviewed by A. E. Emerson.

Valency and Molecular Structure, E. Cartmell and G. W. A. Fowler (Academic Press; Butterworths). Reviewed by L. Pauling.

Treatise on Invertebrate Paleontology, pt. F, *Coelenterata*, R. C. Moore, Ed. (Geological Society of America and University of Kansas Press). Reviewed by L. H. Hyman.

Handbuch der Physik, vol. 1, *Mathematical Methods*, S. Flügge, Ed. (Springer). Reviewed by E. P. Wigner.

Electrochemical Affinity, P. Van Rysselberghe (Hermann). Reviewed by P. Delahay.

Introduction to Mathematical Logic, vol. 1, A. Church (Princeton University Press). Reviewed by J. Turner.

Chemistry of Carbon Compounds, vol. III, pt. B, *Aromatic Compounds*, E. H. Rodd, Ed. (Elsevier). Reviewed by E. Leete.

21 December

Microscopium, M. Rooseboom (National Museum for the History of Science, Leiden). Reviewed by O. W. Richards.

Flow of Gases through Porous Media, P. C. Carman (Academic Press; Butterworths). Reviewed by J. M. DallaValle.

Air Pollution Handbook, P. L. Magill, F. R. Holden, and C. Ackley, Eds. (McGraw-Hill). Reviewed by L. Silverman.

Determination of Organic Compounds, K. G. Stone (McGraw-Hill). Reviewed by R. H. Eastman.

Computers, E. C. Berkeley and L. Wainwright (Reinhold; Chapman & Hall). Reviewed by W. W. Youden.

The Image, K. E. Boulding (University of Michigan Press). Reviewed by E. Larrabee.

28 December

Statistical Mechanics, Principles and Selected Applications, T. L. Hill (McGraw-Hill). Reviewed by D. ter Haar.

Fundamental Concepts of Higher Algebra, A. A. Albert (University of Chicago Press). Reviewed by W. Jacobs.

Antarctica in the International Geophysical Year, Geophysical Monograph No. 1 (American Geophysical Union). Reviewed by F. T. Davies.

Topics in Number Theory, vols. 1 and 2, W. J. LeVeque (Addison-Wesley). Reviewed by H. B. Mann.

Begegnungen mit dem Vormenschen, G. H. R. von Koenigswald (Eugen Diederichs). Reviewed by H. L. Movius, Jr.

Experimental Stress Analysis in the U.S.A. and Canada, Department of Scientific and Industrial Research (H.M. Stationery Office).

High Energy Nuclear Physics, Proceedings of the Sixth Annual Rochester Conference 3–7 Apr. 1956, J. Ballam, V. L. Fitch, T. Fulton, K. Huang, R. R. Rau, and S. B. Treiman, Eds. (Interscience). Reviewed by R. O. Haxby.

New Books

The Biological Basis of Human Freedom. Theodosius Dobzhansky. Columbia University Press, New York, 1956. 139 pp. $2.95.

Creative Communication. Edwin Laird Cady. Reinhold, New York; Chapman & Hall, London, 1956. 158 pp.

Induction Heating Practice. A handbook on the high-frequency induction process for all concerned with engineering production. D. Warburton-Brown. Philosophical Library, New York, 1956. 192 pp. $10.

Engineering Inspection, Measurement and Testing. H. C. Town and R. Colebourne. Philosophical Library, New York, 1956. 192 pp. $8.75.

Social Characteristics of Urban and Rural Communities, 1950. Otis D. Duncan and Albert J. Reiss, Jr. Census Monograph Series. Wiley, New York; Chapman & Hall, London, 1956. 421 pp. $6.50.

Physics for Everybody. Germaine and Arthur Beiser. Dutton, New York, 1956. 191 pp. $3.50.

The Origins and Prehistory of Language. G. Revesz. Translated by J. Butler. Philosophical Library, New York, 1956. 240 pp. $7.50.

Research in the Effects and Influences of the Nuclear Bomb Test Explosions. pts. I and II. Compiled by the Committee for Compilation of Report on Research in the Effects of Radioactivity. Japan Society for the Promotion of Science, Ueno, Tokyo, 1956 (order from Stechert-Hafner, New York 3). 1824 pp. $26.50.

Essentials of Histology. Margaret M. Hoskins and Gerrit Bevelander. Mosby, St. Louis, ed. 3, 1956. 254 pp. $4.

Educating Spastic Children. The education and guidance of the cerebral palsied. F. Eleanor Schonell. Philosophical Library, New York, 1956. 242 pp. $6.

Work, Workers and Work Measurement. Adam Abruzzi. Columbia University Press, New York, 1956. 318 pp. $7.50.

Introduction to Solid State Physics. Charles Kittel. Wiley, New York; Chapman & Hall, London, ed. 2, 1956. 617 pp. $12.

Petrographic Model Analysis. An elementary statistical appraisal. Felix Chayes. Wiley, New York; Chapman & Hall, London, 1956. 113 pp. $5.50.

Preparing for Motherhood. A manual for expectant parents. Samuel R. Meaker. Year Book, Chicago, 1956. 196 pp.

A Practical Manual of Medical and Biological Staining Techniques. Edward Gurr. Interscience, New York, ed. 2, 1956. 451 pp. $6.50.

Science and Economic Development: New Patterns of Living. Richard L. Meirer. Technology Press, Cambridge, Mass.; Wiley, New York; Chapman & Hall, London, 1956. 266 pp. $6.

Changes of State. A mathematical-physical assessment. H. N. V. Temperley. Cleaver-Hume, London; Interscience, New York, 1956. 324 pp. $7.50.

The Nature of Brucellosis. Wesley W. Spink. University of Minnesota Press, Minneapolis, 1956. 464 pp. $8.

The Future of Arid Lands. Papers and recommendations from the International Arid Lands Meeting. Publ. No. 43. Gilbert F. White, Ed. American Association for the Advancement of Science, Washington, 1956. $6.75; members, $5.75.

Discovery of the Elements. Mary E. Weeks. Henry M. Leicester, Ed. Journal of Chemical Education, Easton, Pa., ed. 6, 1956. 910 pp. $10.

Methods of Chemical Analysis for Soil Survey Samples. Soil Bureau Bull. 12. A. J. Metson. New Zealand Department of Scientific and Industrial Research, Wellington, 1956. 208 pp. 30s.

The Scientific Thought of Henry Adams. Henry Wasser. The Author, University of Salonika, Greece, 1956. 127 pp.

Minado. A tale of the Quebec wilderness. Erle Wilson. Appleton-Century-Crofts, New York, 1956. 191 pp. $3.50.

Up-Hill All the Way, the Life of Maynard Shipley. Miriam Allen DeFord. Antioch Press, Yellow Springs, Ohio, 1956. 255 pp. $4.

Disposal of Sewage and other Water-Borne Wastes. Karl Imhoff, W. J. Muller, D. K. B. Thistlethwayte. Based on a translation of Imhoff's *Taschenbuch der Stadtentwaesserung*, ed. 16, 1956. Butterworths, London, 1956. 347 pp. 45s.

Contributions to the Theory of Nonlinear Oscillations. vol. III. S. Lefschetz. Princeton University Press, Princeton, N.J., 1956. 285 pp. $4.

Engineering Analysis. A survey of numerical procedures. Stephen H. Crandall. McGraw-Hill, New York, 1956. 416 pp. $9.50.

Concise Anatomy. Linden F. Edwards. McGraw-Hill, New York, ed. 2, 1956. 502 pp. $7.50.

Philosophy of Science. pt. 1, *Science in General.* Duquesne Studies, Philosophical Ser. 6. P. Henry van Laer in collaboration with Henry J. Koren. Duquesne University, Pittsburgh, Pa.; Nauwelaerts, Louvain, Belgium, 1956. 164 pp. Cloth, $3.75; paper, $3.

Technology and Engineering. Reactor coolants, moderators, heat transfer, reactor chemistry and corrosion of reactor materials. R. Hurst and S. McLain, Eds. McGraw-Hill, New York; Pergamon Press, London, 1956. 420 pp. $12.

Dendroclimatic Changes in Semiarid America. Edmund Schulman. University of Arizona Press, Tucson, 1956. 142 pp. $3.

An Introduction to Matrix Tensor Methods in Theoretical and Applied Mechanics. Sidney F. Borg. Edwards, Ann Arbor, Mich., 1956. 202 pp. $4.75.

Lectures on Rock Magnetism. Being the second Weizmann Memorial Lectures, December, 1954. P. M. S. Blackett. Weizmann Science Press of Israel, Jerusalem, 1956. 131 pp. $5.

Conference on Tissue Fine Structure. Arden House, Harriman, N.Y. 16–18 Jan. 1956. Keith R. Porter, Ed. *The Journal of Biophysical and Biochemical Cytology*, vol. 2, No. 4, pt. 2, suppl. Rockefeller Institute for Medical Research, New York, 1956. 454 pp. $5.

Biochemical Techniques, a Laboratory Manual. F. M. Strong. Burgess, Minneapolis, 1956. 78 pp. $3.

The Rabbit in Experimental Physiology. Harold M. Kaplan. Scholar's Library, New York, 1956. 69 pp. $2.50.

General Relativity and Cosmology. vol. 4 of The International Astrophysics Ser. G. C. McVittie. Wiley, New York, 1956. 198 pp. $9.

Fundamental Concepts of Higher Algebra. A. Adrian Albert. University of Chicago Press, Chicago, 1956. 165 pp. $6.50.

They've Got Your Number. Robert Wernick. Norton, New York, 1956. 124 pp. $2.95.

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Education in the U.S.A. A comparative study. W. Kenneth Richmond. Philosophical Library, New York, 1956. 227 pp. $4.50.

Handbuch der Physik. Band XXI, *Gas Discharges I.* S. Flugge, Ed. Springer, Berlin, 1956. 683 pp. DM. 105.50.

Topics in Number Theory. vols. 1 and 2. William J. LeVeque. Addiso-Wesley, Reading, Mass., 1956. vol. 1, 198 pp., $5.50; vol. 2, 270 pp., $6.50.

Photoconductivity Conference. Held at Atlantic City, 4–6 Nov. 1954. Sponsored by the University of Pennsylvania, Radio Corporation of America, and Office of Naval Research. R. G. Breckenridge, Chairman, Editorial Committee. Wiley, New York; Chapman & Hall, London, 1956. 653 pp. $13.50.

Chemical Engineering Practice. vol. 1, *General.* Herbert W. Cremer, Ed. Academic Press, New York; Butterworths, London, 1956. 494 pp. $13.30 per volume on orders for complete set; $17.50.

The Image of the Heart. And the principle of synergy in the human mind. Daniel E. Schneider. International Universities Press, New York, 1956. 267 pp. $6.

The Earth We Live on. The story of geological discovery. Ruth Moore. Knopf, New York, 1956. 416 pp. $6.

Polymer Solutions. H. Tompa. Academic Press, New York; Butterworths, London, 1956. 325 pp. $8.50.

Rattlesnakes. Their habits, life histories, and influence on mankind. vols. 1 and 2. Laurence M. Klauber. Published by University of California Press (for the Zoological Society of San Diego), Berkeley. 1956. 1476 pp. $17.50 per set.

Fundamentals of Immunology. William C. Boyd. Interscience, New York, ed. 3, 1956. 776 pp. $10.

A Space Traveler's Guide to Mars. I. M. Levitt. Holt, New York, 1956. 175 pp. $3.95.

Arctic Frontiers. United States explorations in the far North. John E. Caswell. University of Oklahoma Press, Norman, 1956. 232 pp. $3.75.

Geology of the Delaware Valley. Horace G. Richards. Mineralogical Society of Pennsylvania, Philadelphia, 1956. 106 pp. $2.50.

On Freedom and Free Enterprise. Essays in honor of Ludwig von Mises. Presented on the occasion of the fiftieth anniversary of his doctorate, 20 February 1956. Mary Sennholz, Ed. Van Nostrand, Princeton, N.J., 1956. 333 pp. $3.50.

Challenge of the Andes. The conquest of Mount Huantsañ. C. G. Egeler and T. De Booy. Translated by W. E. James. McKay, New York, 1956. 203 pp. $4.50.

The Intellectual Life of Colonial New England. Samuel Eliot Morison. New York University Press, New York, 1956. 288 pp. $4.95.

Diseases of Field Crops. James G. Dickson. McGraw-Hill, New York, ed. 2, 1956. 517 pp. $8.50.

Applied Metallurgy for Engineers. Malcolm S. Burton. McGraw-Hill, New York, 1956. 407 pp. $7.50.

Chromium. vol. II, *Metallurgy of Chromium and Its Alloys.* American Chemical Society Monogr. Ser. Marvin J. Udy. Reinhold, New York; Chapman & Hall, London, 1956. 402 pp. $11.

J. C. Poggendorff Biographisch-Literarisches Handwörterbuch der Exakten Naturwissenschaften. Band VIIa, Teil I, A–E; 2 parts (pp. 257–384 and pp. 385–547). Akademie, Berlin, 1956. DM. 16 and DM. 22.50.

Astronomical Optics and Related Subjects, Proceedings of a Symposium. Zdenek Kopal. North-Holland, Amsterdam; Interscience, New York, 1956. 428 pp. $12.50.

A Popular History of Music. Carter Harman. Dell, New York, 1956. 352 pp. Paper, $0.50.

The Stress of Life. Hans Selye. McGraw-Hill, New York, 1956. 324 pp. $5.95.

Rayleigh's Principles and Its Applications to Engineering. The theory and practice of the energy method for the approximate determination of critical loads and speeds. G. Temple and W. G. Bickley. Dover, New York, 1956 (unabridged and unaltered republication of ed. 1). Paper, $1.50.

Numerical Integration of Differential Equations. Albert A. Bennett, William E. Milne, Harry Bateman. Dover, New York, 1956 [unabridged unaltered republication of the report (Bulletin 92) of the Committee of the Division of Physical Sciences of the National Research Council]. Paper, $1.35.

Lectures on the Icosahedron and the Solution of Equations of the Fifth Degree. Felix Klein. Translated by George G. Morrice. Dover, New York, ed. 2 and rev. ed., 1956. 289 pp. Paper, $1.85.

Handbook of Biological Data. William S. Spector, Ed. Prepared under the direction of the Committee on the Handbook of Biological Data. Saunders, Philadelphia, 1956. 584 pp. $7.50.

Calder Hall. The story of Britain's first atomic power station. Kenneth Jay. Harcourt, Brace, New York, 1956. 88 pp. $3.

Physical Chemistry for Students of Pharmacy and Biology. S. C. Wallwork. Longmans, Green, New York, 1956. 307 pp. $5.

New Era of Flight. Aeronautics simplified. Lewis Zarem and Robert H. Maltby. Dutton, New York, 1956. 176 pp. $3.75.

Proceedings of the Third Berkeley Symposium on Mathematical Statistics and Probability. Held at the Statistical Laboratory, University of California, December, 1954, July and August, 1955. vol. I, *Contributions to the Theory of Statistics.* 208 pp. $6. vol. III, *Contributions to Astronomy and Physics.* 252 pp. $6.25. Jerzy Neyman, Ed. University of California Press, Berkeley, 1956.

Psychology, Psychiatry and the Public Interest. Maurice H. Drout, Ed. University of Minnesota Press, Minneapolis, 1956. 217 pp. $4.

Handbuch der Physik. Band XVII, *Dielectrics.* S. Flugge, Ed. Springer, Berlin, 1956. 406 pp. DM. 94.

Economic Analysis. Edmund Whittaker. Wiley, New York; Chapman & Hall, London, 1956. 460 pp. $6.50.

The Oscilloscope at Work. A. Haas and R. W. Hallows. Iliffe, London; Philosophical Library, New York, 1956. 171 pp. $10.

Reference Data for Radio Engineers. International Telephone and Telegraph Corp. New York, ed. 4, 1956. 1121 pp. $6.

Meetings

February

18–20. American Educational Research Assoc., annual, Atlantic City, N.J. (F. W. Hubbard, AERA, 1201 16 St., NW, Washington 6.)

18–22. American Soc. of Civil Engineers, Jackson, Miss. (W. H. Wisely, ASCE, 33 W. 39 St., New York 18.)

18–22. Endocrinology: Hormones in Blood, Ciba Foundation Colloquium (by invitation), London, England. (G. E. W. Wolstenholme, 41 Portland Pl., London, W.1.)

21–23. National Soc. of College Teachers of Education, annual, Chicago, Ill. (C. A. Eggertsen, School of Education, Univ. of Michigan, Ann Arbor.)

23. American Mathematical Soc., New Haven, Conn. (J. H. Curtiss, AMS, 190 Hope St., Providence 6, R.I.)

23. Oregon Acad. of Science, annual, Monmouth. (F. A. Gilfillan, Oregon State College, Corvallis.)

24–28. American Inst. of Mining, Metallurgical and Petroleum Engineers, annual, New Orleans, La. (E. O. Kirkendall, AIME, 29 W. 39 St., New York 18.)

24–28. International College of Surgeons, 10th biennial cong., Mexico, D.F., Mexico. (M. Thorek, ICS, 850 W. Irving Park Rd., Chicago 13, Ill.)

25–28. American Soc. of Heating and Air-Conditioning Engineers, Chicago, Ill. (A. V. Hutchinson, ASHAE, 62 Worth St., New York 13.)

26–28. Western Joint Computer Conf., Los Angeles, Calif. (M. J. Mendelson, Norden-Ketay Corp., 13210 Crenshaw Blvd., Gardena, Calif.)

March

1–2. American Physical Soc., Norman, Okla. (K. K. Darrow, Columbia Univ., New York 27.)

1–3. National Wildlife Federation, annual, Washington, D.C. (C. H. Callison, 232 Carroll St., NW, Washington 12.)

3–6. American Inst. of Chemical Engineers, White Sulphur Springs, W.Va. (F. J. Van Antwerpen, AIChE, 25 W. 45 St., New York 36.)

3–9. American Soc. of Photogrammetry, 23rd annual, jointly with American Cong. on Surveying and Mapping, 17th annual, Washington, D.C. (C. E. Palmer, ASP, 1515 Massachusetts Ave., NW, Washington 5.)

4. Wildlife Soc., annual, Washington, D.C. (D. L. Leedy, Fish and Wildlife Service, Dept. of the Interior, Washington 25.)

4–6. National Biophysics Conf., Columbus, Ohio. (H. P. Schwan, School of Medicine, Univ. of Pennsylvania, Philadelphia 4.)

4–8. Analytical Chemistry and Applied Spectroscopy, Pittsburgh, Pa. (L. M. Melnick, U.S. Steel Corp., Applied Research Lab., Monroeville, Pa.)

7–9. American Orthopsychiatric Assoc., 34th annual, Chicago, Ill. (M. F. Langer, AOA, 1790 Broadway, New York 19.)

7–9. Fundamental Cancer Research, 11th annual symp., Houston, Tex. (L. Dmochowski, M. D. Anderson Hospital, Texas Medical Center, Houston 25.)

7–9. Optical Soc. of America, semiannual, New York, N.Y. (S. S. Ballard, Scripps Inst. of Oceanography, San Diego 52, Calif.)

10–16. Nuclear Engineering and Science Cong., 2nd, Philadelphia, Pa. (Engineers Joint Council, 29 W. 39 St., New York 18.)

11–15. National Assoc. of Corrosion Engineers, 13th annual, St. Louis, Mo. (R. T. Effinger, Shell Oil Co., Deer Park Refinery, Houston, Tex.)

13–15. Society of Exploration Geophysics, 10th annual midwestern, Fort Worth, Tex. (G. A. Grimm, Tide Water Associated Oil Co., Box 2131, Midland, Tex.)

14. Effect of Radiation on Foods, Assoc. of Vitamin Chemists, Chicago, Ill. (M. Freed, Dawe's Laboratories, Inc., 4800 S. Richmond St., Chicago 32.)

15. Fats in Human Nutrition, AMA symp., New Orleans, La. (Council on Foods and Nutrition, American Medical Assoc., 535 N. Dearborn, Chicago 10, Ill.)

18–21. Institute of Radio Engineers, natl. convention, New York, N.Y. (B. Warriner, IRE, 1 E. 79 St., New York 21.)

19–21. American Meteorological Soc., 151st national, Chicago, Ill. (K. C. Spengler, AMS, 3 Joy St., Boston 8, Mass.)

20–22. National Health Forum, Cincinnati, Ohio. (National Health Council, 1790 Broadway, New York 19.)

20–23. National Science Teachers Assoc., annual, Cleveland, Ohio. (R. H. Carleton, NSTA, 1201 16 St., NW, Washington 6.)

21–23. American Physical Soc., Philadelphia, Pa. (K. K. Darrow, APS, Columbia Univ., New York 27.)

21–23. International Assoc. for Dental Research, annual, Atlantic City, N.J. (D. Y. Burrill, 129 E. Broadway, Louisville 2, Ky.)

21–23. Michigan Acad. of Science, Arts and Letters, annual, Detroit. (R. F. Haugh, Dept. of English, Univ. of Michigan, Ann Arbor.)

22–23. Heart: Law-Medicine Problem, Cleveland, Ohio. O. Schroeder, Jr., Law-Medicine Center, Western Reserve Univ., Cleveland 6.)

23–28. American Soc. of Tool Engineers, 25th annual, Houston, Tex. (R. Gebers, 10700 Puritan, Detroit 38, Mich.)

24–27. American Assoc. of Dental Schools, annual, Atlantic City, N.J. (M. W. McCrea, 42 S. Greene St., Baltimore 1, Md.)

25–28. American Acad. of General Practice, 9th annual scientific assembly, St. Louis, Mo. (M. F. Cahal, AAGP, Volker Blvd. at Brookside, Kansas City 12, Mo.)

25–29. Western Metal Exposition and Congress, 10th, Los Angeles, Calif. (W. H. Eisenman, 7301 Euclid Ave., Cleveland 3, Ohio.)

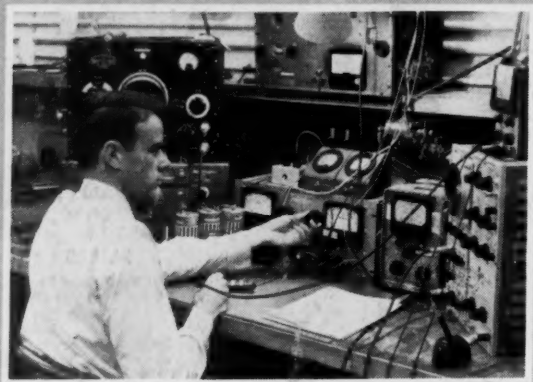
26–28. Mechanisms for the Development of Drug Resistance in Microorganisms, Ciba Foundation Symp. (by invitation), London, England. (G. E. W. Wolstenholme, 41 Portland Pl., London, W.1.)

26–28. Weather Radar Conf., 6th, sponsored by American Meteorological Soc., Cambridge, Mass. (K. C. Spengler, 3 Joy St., Boston 8, Mass.)

27–29. American Power Conf., 19th annual, Chicago, Ill. (R. A. Budenholzer, Illinois Inst. of Technology, 35 W. 33 St., Chicago 16.)

27–29. National Committee on Alcoholism, annual, Chicago, Ill. (Miss E. Jensen, NCA, 2 E. 103 St., New York 29.)

31–9. Pan American Cong. of Social Work, 3rd, San Juan, P.R. (Mrs. M. Velez de Perez, Apartado 3271, San Juan.)



RESEARCH AND DEVELOPMENT

PILOT LINE PRODUCTION

FINAL ASSEMBLY

TESTING IN SCREEN ROOM

COMMUNICATIONS at Ramo-Wooldridge

Communications activities at The Ramo-Wooldridge Corporation include research, development, and manufacture of advanced types of radio communication systems, ground-reference navigation systems, and electronic countermeasure systems. Major programs are in progress in each of these fields.

New and unusual techniques have been employed to provide systems having a high order of security in the transmission of information, broad flexibility in combating unfavorable signal propagation conditions, and substantially greater information capacity per operating channel.

Some of the techniques used have made possible an increased range for given levels of transmitter power and reliability of communications. Others have provided specific advantages in very long distance communications or in operational situations requiring unique signaling capabilities. Developments in navigation systems have resulted in new equipment that is suitable for the guidance of aircraft at long ranges from their bases.

In the work currently under way, some systems are in the laboratory development stage, some in the flight test stage, some are in production. Several types of systems developed and manufactured by Ramo-Wooldridge are in extensive operational use.

Openings exist for engineers and scientists in these fields of communications activities:

- Systems study and analysis
- Airborne transmitters
- Transistorized video and pulse circuitry
- Airborne receivers
- Reconnaisance systems
- Digital communications systems

The Ramo-Wooldridge Corporation

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